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The Apollo Medical Operations Project: Recommendations to Improve Crew Health and Performance for Future Exploration Missions and Lunar Surface Operations

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Abstract

Introduction. Medical requirements for the future Crew Exploration Vehicle (CEV), Lunar Surface Access Module (LSAM), advanced Extravehicular Activity (EVA) suits and Lunar habitat are currently being developed. Crews returning to the lunar surface will construct the lunar habitat and conduct scientific research. Inherent in aggressive surface activities is the potential risk of injury to crewmembers. Physiological responses and the operational environment for short forays during the Apollo lunar missions were studied and documented. Little is known about the operational environment in which crews will live and work and the hardware will be used for long-duration lunar surface operations.Additional informantion is needed regarding productivity and the events that affect crew function such as a compressed timeline. The Space Medicine Division at the NASA Johnson Space Center (JSC) requested a study in December 2005 to identify Apollo mission issues relevant to medical operations that had impact to crew health and/or performance. The operationally oriented goals of this project were to develop or modify medical requirements for new exploration vehicles and habitats, create a centralized database for future access, and share relevant Apollo information with the multiple entities at NASA and abroad participating in the exploration effort.

Methods. A review of medical operations during Apollo missions 7 through 17 was conducted. Ten categories of hardware, systems, or crew factors were identified during preliminary data review generating 655 data records which were captured in an Access® database. The preliminary review resulted in 280 questions which were posed to surviving Apollo crewmembers using mail, face-to-face meetings, phone communications, or online interactions. Crew member responses to these questions formed the basis for recommendations to items in each of the categories.

Results. 14 of 22 surviving Apollo astronauts (64%) participated in the project. Approximately 236 pages of responses to the questions were generated based on the Apollo experiences, with 107 recommendations offered for future vehicles, habitats, EVA suits, and lunar surface operations.

Discussion. The Apollo medical operations recommendations are being incorporated into the exploration mission architecture at various levels: 49 recommendations either validated, revised or created new requirements, 4 are currently in practice, 15 are being evaluated, and 44 are being considered. A centralized database has been developed, and the recommendations have been presented to the different organizations involved with building the new vehicles, habitats, suits, or systems that may impact crew health and performance.

Conclusions. The Apollo crewmembers' input has proved to be an invaluable resource to a multitude of departments beyond space medicine. We will continue soliciting input from this group as we evolve and refine requirements for future exploration missions.

Introduction

The Apollo program, which began in January of 1966, was comprised of 18 missions: 12 crewed missions (including the Apollo 204 mission with Virgil "Gus" Grissom, Ed White, and Roger Chaffee) and six uncrewed missions which tested the capabilities of the Saturn rocket components[6]. The Apollo 7 mission heralded the first successful crewed mission, and in July of 1969, Apollo 11 fulfilled John F. Kennedy's mandate to send a man to the Moon and return him safely home[7]. Twenty-six men flew Apollo missions, including four repeat flyers. Of the manned missions, six flights conducted between July 1969 and December 1972 successfully landed 12 humans on the lunar surface and returned them to the Earth.

In January 2004, President George W. Bush committed the United States to the further exploration of space[8]. This new vision for space exploration has the benefit of the cumulative knowledge and experience gained from the Apollo program. The exploration effort will require the development of new vehicles to transport crews from Earth to the lunar surface and for transportation while on the moon. In addition, crew will need extravehicular activity (EVA) suits and extended duration habitation elements for the lunar surface operations[10]. The Crew Exploration Vehicle (CEV) and Lunar Surface Access Module (LSAM) though slightly larger, will bear many similarities to the Apollo Command Module (CM) and Lunar Module (LM). The EVA suits may serve the dual function of a launch and entry suit as well as the lunar surface suit. Lunar habitation is a new frontier, enabling humans to live on the Moon for extended periods in order to conduct science experiments and use the lunar environment for in-situ resource utilization (ISRU).

During previous studies, Apollo astronauts provided input into the engineering and mechanical aspects of EVA suit system designs [2]. However, no study has specifically addressed the impact of the Apollo vehicles, hardware, and systems on crew health or performance throughout all mission phases, including lunar surface operations and the influence of that impact on the new exploration vehicles and mission architectures.

To identify Apollo mission issues that had impact to crew health and/or performance and were relevant to medical operations, the Space Medicine Division requested a study in December of 2005. The goals of this project were to develop or modify medical requirements for new vehicles and habitats, create a centralized medical operations database for future access, and provide this knowledge to the multiple directorates at NASA-JSC participating in the exploration effort. Secondary objectives included using this information to validate current requirements and refresh knowledge regarding lunar operations in an effort to reduce both programmatic risk and risk to crew health, productivity, and safety. The Space Medicine Division study and this paper are not intended to be a review of information contained in previous publications, such as *Biomedical Results of Apollo*.

Due to the multidisciplinary operational focus of this study, the primary audience targeted is diverse. The audience includes flight surgeons, engineers, and scientists developing the medical requirements for exploration vehicles, habitats, and suits, the mission planners developing crew timelines, and experts supporting behavioral health and performance. Various aspects of this report will be of interest to a broader readership outside the medical operations community. Therefore, the report is written in a medically non-attributable format accessible to anyone with an interest in the Apollo program.

The Apollo Medical Operations Project was headed by Rick Scheuring, DO, MS, UTMB/Wyle Labs flight surgeon, James D. Polk, DO, MS, Manager of Medical Operations at JSC and Josef Schmid, MD, also with Medical Operations at JSC. The team included other flight surgeons from the Medical Operations office at JSC and University of Texas Medical Branch, Galveston, as well as project scientists and engineers within the Space Life Sciences Directorate (SLSD) and the Mission Operations Directorate (MOD) at JSC. Participation of the Apollo astronauts was solicited through the Medical Operations Division.The team would like to express an acknowledgement of the enormity of the task and an appreciation to the Apollo crews for discussing their missions which occurred at a time when most of the team members were still children.

Methods

This section addresses the spectrum of approaches taken to assimilate, categorize, and assess the data.

Background Research

Background research was undertaken by the Apollo Medical Operations Project team to maximize the benefits from the study. The approach taken in this study consisted of the following:

- Identify specific medical-related problems, if any, in each area associated with the operational environment during all mission phases
- Define the impact on crew health and/or performance
- Identify problems that recurred or were fixed on subsequent missions
- Develop an integrated, comprehensive set of questions that could be used in a face-to-face meetings with the Apollo astronauts

The impetus to take these steps to “do our homework” before meeting with the astronauts came from the Apollo crewmembers themselves[11]. The crews voiced annoyance at discussing subjects or responding to questions that previously had been published. Therefore, it was incumbent upon the team to research areas and develop questions not previously documented.

Review of Apollo resources pertaining to Medical Operations and the sources of data included: Apollo 7-17 medical mission debriefs; Apollo 7-17 flight surgeon logs; Apollo 7-17 biomedical engineer logs; Apollo 7-17 mission commentaries; Apollo mission reports (11-17)[13]; Apollo lunar surface journals (11-17)[3]; preliminary science reports (11-17)[12]; the Apollo lecture series[11]; Apollo videos; NASA technical memorandums, related papers[2,14,15,16,17,18]; and personal communications with the crewmembers through email, phone or direct contact. These materials were reviewed by the team to understand the Apollo astronauts’ experiences and the issues impacting their health and/or performance as previously reported. It is important to note that the medical debriefs and flight surgeon/BME logs are considered medically confidential material and subject to the Medical Privacy Act of 1974. All other resources are available to the public. It is equally important to note that some issues identified in the debriefs were detailed in the crew logs, crew questionnaires, or air-to-ground communications but were unavailable. Every attempt was made to fill in the missing information from available resources for this study.

After reviewing historical data, the team identified eleven categories within the operational environment occurring during Apollo 7-17 that had impacts to crew health and/or performance. The data assembled into these categories formed the basis of the questions used to interview the Apollo astronauts. The categories included EVA mobility unit (EMU) and EVA suit issues; lunar surface operations; inflight illnesses, medical kit, medications, or bioinstrumentation; environmental (vehicle); radiation; exercise; food and nutrition; performance, human factors, crew schedule; launch, re-entry, and recovery; and flight surgeon-crew interactions. Certain well-documented areas relating to crew health or performance, such as lunar dust, were identified but not covered in detail during this study. Likewise, areas that affected the Apollo crews but were not relevant to the new vehicle design, such as the Apollo water chlorination system, were identified in the data collection but were not addressed during the face-to-face meetings.

Data Collection

The historical data collected was organized and compiled into an Access® database (Appendix A). This database facilitated the search capabilities of the team in identifying areas that had health and/or performance impacts. The data was organized by mission, source of information, topic (category), medical/hardware issue, crewmember involved (if applicable), description of the problem, general comments about the issue, and resolution/reoccurrence. From this body of data questions related to the issue were generated. The team used this method, to create 655 data records. An example of one record is provided in figure 1. Note that any attributable astronaut medical information contained in Appendix A has been removed for the purpose of this paper and exists as a separate document.

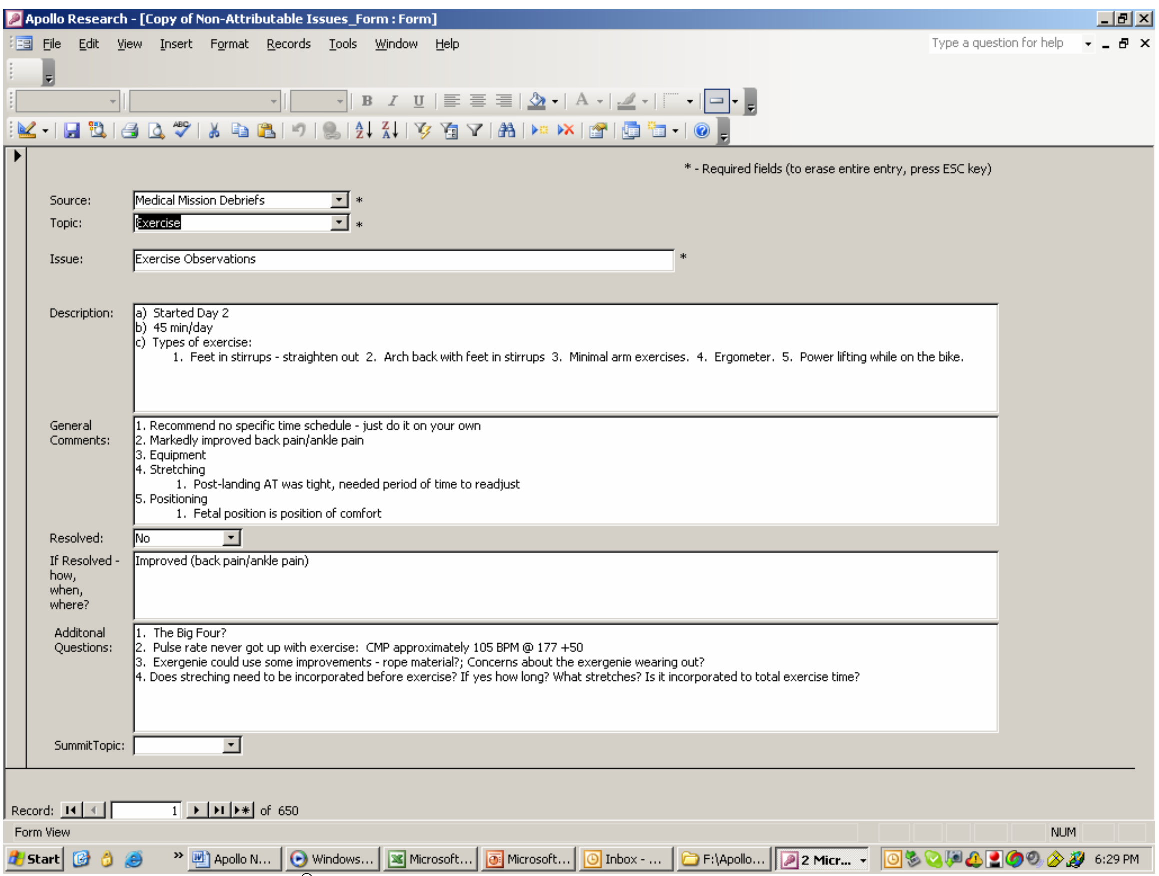

Figure 1. Sample Access® data record from the Apollo Medical Operations Project.

Panel Questions

Questions were generated within the 11 categories from the historical data search effort and input from operational and research disciplines associated with each category (Appendix B). These questions were augmented with others impacting crew health or performance solicited from discipline leads in each category. The categorized questions were reviewed by flight surgeons and current astronaut physicians at JSC for relevance and operational applicability to the exploration effort. This resulted in a final list of 280 questions used during the face-to-face meeting with the Apollo astronauts.

Face-to-Face Summit

The face-to-face summit with the Apollo astronauts was held June 2006 in Houston, Texas. Per the crewmembers' request, days 1 & 2 were closed sessions limited to Apollo crew, the current flight surgeon cadre, and astronaut physicians. Day 3 was limited to invited guests and the Apollo flight surgeons. Of the original 29 Apollo astronauts, 22 survive today and were invited to participate in the face-to-face summit (Appendix E). Dr. Joseph Kerwin, who served as CAPCOM for Apollo 13 and astronaut physician on Skylab I, was a project team member and invited to participate as an astronaut. The invited guests for Day 3 submitted questions to the Apollo Medical Operations Project team prior to the meeting to insure the appropriateness of the question and to facilitate interaction with the crewmembers during the session.

Prior to the panel question discussion on days 1 and 2, the project team presented informational briefings to achieve the intended outcome of the meeting. The two-fold purpose of the meetings was to capture the experiences of the Apollo astronauts to validate findings from the historical data search and to project applicable aspects of Apollo operational experience to the exploration initiative. The project team presented the issues that faced the crews during their missions from the historical data research to increase their awareness of the current knowledge base. It also served to stimulate memories garnered three and a half decades ago. The presentation concluded with a discussion of the exploration architecture to familiarize the participants with the new strategies and mission plans.

The panel discussions were held with the astronauts and project team members meeting in one room. A professional transcriptionist recorded all comments from the astronauts and later organized the responses with the corresponding questions. The day-3 session was conducted in a similar manner by the team and transcriptionist. This document was then reviewed by the project team for accuracy and clarification. Notes taken by the panel team during the question sessions were added to the document as necessary.

Post-Summit Review and Validation

The purpose of the post-summit phase was to compile the accumulated responses to the panel questions and organize into a comprehensive report (Appendix B). Apollo astronauts who participated in the face-to-face summit reviewed and validated the report. They also submitted additional input and points of clarification. After review by the project team, the updated version including recommendations was then submitted to all the Apollo astronauts providing an opportunity for an additional six crewmembers not attending the face-to-face meetings to participate. Responses can be found in Appendix G.

Results

Data

Sixty-four percent (14 of 22) of the surviving Apollo astronauts participated in the project. The combined crewmember responses to the 280 questions generated from the background research resulted in 236 pages of data. A comprehensive review of all the responses from the astronaut sources revealed 107 recommendations from statements in all 11 categories that the group made to the questions as shown in Appendix C. The input shown in table 1 formed the basis of the Apollo Medical Operations Project recommendations.

Number of attendees	**8**
Post-summit full responses	7
Total number of Apollo astronauts input	14
Number of Apollo astronauts available	22

***Table 1**. Astronaut attendance and participation at Apollo Summit.*

The panel discussion questions and answers document is broken down into the number of questions per category and the responses from the post-summit participants in Table 2. Note that this section is only post-summit responses and does not include the eight summit attendees' responses, which could not be individualized.

Input from 14 of 22 astronauts (summit and post-summit)	64%		
	# of Questions	Post-Summit # of Responses	Post-Summit Response Rate %
EMU/EVA Suit	63	30	8.06%
Lunar Surface Ops	36	20	9.26%
In-flight Illnesses/Medications	16	24	25.00%
Medical Kit	3	4	22.00%
Bioinstrumentation	3	5	27.78%
Environmental Impacts	35	75	35.71%
Radiation	5	4	13.33%
Exercise	20	33	27.50%
Food Nutrition	28	76	45.24%
Performance/Human Factors	16	48	50.00%
Crew Work-Rest Schedules	10	30	50.00%
Launch Recovery	34	121	59.31%
Flight Surgeon Crew Interaction	2	7	58.33%
General Questions	14	31	36.90%
Totals	**285**	**508**	

Table 2*. Number of questions in each of the 11 categories with number and rate of post-summit participant responses. Note that the number of categories is further broken down into subsections of the main category where bolded.*

Operational and Research Recommendations by Category

EMU/EVA Suit

1. *Improve glove flexibility, dexterity, fit*. According to the Apollo lunar crews, the most fatiguing part of surface EVA tasks was repetitive gripping. Regarding the glove, one crewmember stated, "*Efficiency was no more than 10% of the use of the hand*." The fingernails tended to be pulled back resulting in separation of the nail from the bed, or onycholysis. Additionally, the skin frequently was abraded from the top of the knuckles. This event took on operational and potentially mission significance as several lunar walkers stated that they would not be able to work in the glove beyond the two-three EVA's they completed due to the swelling and pain over the bony prominences of the metacarpal phalangeal (MCP) and proximal interphalangeal (PIP) joints. It is also interesting to note that the lunar crews stated that they did not experience hand or forearm trauma in training, though muscle fatigue occurred. This was not their experience on the moon. In terms of flexibility and fit, the glove should come as close to Earth-normal dexterity and use of the hands as possible. Lowering the pressure [in the suit] was suggested, i.e. the less strength it takes to manipulate the glove, the less physically tasking to the hand and forearm musculature. This can also be accomplished by reducing the glove bulk by making the bladder thinner. Other glove recommendations included:

- Gloves should be custom designed for each crewmember and should incorporate mechanical closure for gripping
- Designers should consider a wrist seal and depressurized glove
- Robotic power-assisted glove should be used for repetitive tasks
- Glove liners should be worn to prevent skin chaffing and abrasions

A consensus statement made by the Apollo astronauts who participated in the project on the EVA suit issue was that given a fixed budget for suit development and improvement, the funding for the new suit would be best spent in improving the glove. If money is left over for other components, then address those issues, but fix the glove first.

2. *Reduce the mass of the suit by a factor of two*. Once the glove issues have been addressed, reducing the suit mass would help. Despite suit bulkiness, the astronauts cautioned that suit mass were an asset to some extent in the partial gravity environment. It provided an inertial point of reference that allowed them to adapt to 1/6 g. Reducing the suit mass too much would remove the familiarity the crewmembers relied on and may predispose one to injury.

3. *Increase general mobility by a factor of four*. EVA suit mobility was more of an issue in terms of surface locomotion and energy expenditure. The crews often felt they were fighting the resistance in the suit (particularly in the glove). This was fatiguing, especially in the thighs. The astronauts pointed out that the lunar surface is likened to an ocean more than a desert. The undulating surface posed a number of challenges, including ambulating against a suit that did not allow mobility at the hip. Normal human locomotion includes flexion at the hip and the Apollo A7LB did not allow this motion. The crewmember had to bend forward from the knee joint, which demanded considerably more work load on the quadriceps muscles. Therefore, the mobility recommendations centered on adding hip mobility and improved knee flexibility. One comment summed this point well, "*Bending the knee was difficult in the suit. We need a better [more flexible] knee joint*."

Reducing suit pressure would accomplish this to some extent but the crews understood the limitations with using this approach to improving suit mobility alone, namely increasing decompression sickness risk and reducing the margin of safety with a suit puncture. It was also pointed out that lowering suit pressure may remove some of the suit extremity splinting effect and could predispose to limb injury, which was generally not a concern at the Apollo suit pressure.

4. *Lower suit Center of Gravity* (CG). Although this area has garnered considerable attention recently with new suit design, the crews felt it was not a main issue, compared to the glove issues or suit mobility. They reported adapting to the suit CG quickly on the lunar surface, which was described as "*aft and* *slightly high*." A number of crewmembers stated *"Don't make moving the CG your primary priority. Move the CG only if it becomes convenient to do so while taking care of other issues like reducing the mass of the suit, fixing the glove, etc."*

5. *Develop a system that prevents helmet fogging during heavy exertion*. Although the lunar walkers did not experience fogging of their visor while on the Moon, its occurrence could be catastrophic. An example for potential adverse effects due to visor fogging was the Apollo 11 mission. Crewmembers remained in their suits during recovery operations for quarantine concerns. The visor fogged once the command module (CM) was opened to the humid, warm South Pacific air, completely obscuring their vision. One crewmember became very concerned during transfer from the CM to the rescue basket, as he was unable to clear the visor to see where he was going. The implications on the lunar surface are obvious. Visor fogging needs to be eliminated as a concern, especially if a contingency situation occurs where the crewmember is physically exerting him/herself for extended periods of time.

6. *Improve peripheral vision by adding neck ring* (movable joint). The surface crewmembers stated, "*You would always have to turn your body* [and the suit] *to see to the side.*" The astronauts' inability to see their feet during lunar operations made walking difficult at times. Helmet design should allow the astronauts to see their feet while traversing the surface of the moon. Another participant concern was the inability to see their arm during a fall to the side, which occurred with some frequency. A movable neck ring, such as the Navy deep sea diving helmet with rotating neck ring, is a good option and should be considered in the new suit design.

7. *Develop a reliable Heads-up Display* (HUD) *displaying consumables information, limited biomedical* (BIOMED) *data, and navigation on demand*. The crews felt the HUD should primarily present the operational information that you need in an instant, e.g. if you want to see oxygen consumption, you say "oxygen" and it appears on the display. Crew did not feel a pressing need to know their heart rate, metabolic rate, or other physiological information during an EVA as in a continuous display. However, a heads-up display would be acceptable with limited physiological information on demand. A concern expressed by one participant was to avoid increasing the complexity of the system to the point of reducing its reliability.

8. *The lunar boot functioned well and does not need to be improved*. The boot was very comfortable; however, it was slippery on rocks or boulders that had high silica content. This was not a problem generally during the surface operations. Concerns regarding "slipping" in the moon dirt were unfounded. The lunar regolith has a high coefficient of friction. This property helped maintain the crewmembers footing despite its "slippery" or "loose" appearance. There was not concern about ankle sprains or injuries with falls due to the lunar soil.

9. ***Use a self-sealing pressure garment within the suit in case of puncture***. EVA suit puncture hazard was the primary concern of the lunar astronauts, although the risk was considered low. Astronauts suggested that protecting suit occupants from a break in suit integrity was for future research and development activities.

10. ***The drink bag should have capability to contain a high-energy liquid in addition to plain water*****.** The A7LB suit had a 15-ounce drink bag, an amount considered insufficient for the crews on the surface. Typical lunar surface activities may last up to 7.5 hours, but the total time in-suit from don-to-doff could be up to 10 hours. The astronauts strongly agreed the amount of liquid beverage contained in the suit needed to be increased for future crewmembers, including separate capabilities for plain water and a non-caffeinated high-energy drink. Caffeine causes the micturition reflex and could potentially cause dehydration from frequent urination.

11. ***Develop a better in-suit Urine Collection Device*** **(*****UCD*****)** ***that will work in 1/6 g*****.** The UCD provided to the crewmembers for use in the suit was a one-size-fits-all device that worked for some and did not work for others. Urine leaks sometimes resulted in skin irritation.

12. ***The suit should be a low pressure*** **(3.50 psia)*****, single gas system****.* Referring to recommendation #3, the crews stated that testing a lower pressure suit should be considered but suggested a lower limit pressure of 3.50 psia at 100% oxygen.

13. ***Protect the suit zipper function***. The Apollo A7LB suit was a single zipper system, unlike the Gemini suit which was a double-zipper system. The lunar dust was difficult to clear from the zipper and impaired normal function on each subsequent lunar EVA. The abrasive nature of the dust scored the metal connections. The lunar dust exposure did not result in a breach of the sealing capability of the suit; repeated exposures may increase this risk.

Lunar Surface Operations

Among the lunar surface operations recommendations, crew scheduling, feasibility of surface activity commencement, airlock and hatch design were given particular importance for the exploration architecture.

14. ***Schedule crews for two Lunar EVA*** **(LEVA)** ***days on and one day for maintenance, alternating crews throughout the week***. The surface walkers were adamant that surgeons protect the future lunar crews from overwork. Multiple factors allowed the Apollo lunar crews to work and stay awake for long periods of time during their relatively short stay: disruption of normal circadian rhythm influencing wake-sleep cycles; loud ambient noise levels in the lunar module (LM) (the exact background noise level was not measured according to

Jerry Goodman, Apollo vehicle engineer); and crew psychological state, i.e. the lunar astronauts were excited considering their current circumstances. Sleep was described as a couple of hours of “nodding off” on the lunar surface. The astronauts stated that to optimize crew performance for extended stays on the Moon, the schedule should never allow for more than two days of LEVA consecutively without a day of rest. This day would be considered an intravehicular activity (IVA) day spent performing suit maintenance or preparation for future field activity. A crew of four could alternate this schedule thereby protecting the crewmembers from overwork.

15. *The hatch and ingress corridor should be sized appropriately for an inflated 1/6 g pressure suit*. A curious finding during the background research involved reviewing the individual crewmembers metabolic activity during their lunar surface activity. All the crewmembers had notable increases in their metabolic rate during the last half hour of their 3.5 to 7.5 hour LEVA. The initial assumption was that the crews were deconditioned from their micro- and partial gravity exposure thereby reducing their exercise capacity. However, the crews’ stated sudden increase in energy expenditure had to do with the hatch design on the LM: the pressurized suits were too big and bulky to get into the hatch without bending and twisting their bodies. The position of the display keyboard (DSKY) above the hatch also prevented the crews from placing their hands in this area to gain leverage to pull themselves into the LM. This activity usually took several tries to ingress the LM and was quite a fatiguing process. Jerry Goodman, an Apollo vehicle engineer who helped with the LM hatch design, identified that the problem occurred before the vehicle arrived on the Moon. Apparently the hatch design and pressurized suit design, although dependent and initially corroborated, later changed without being communicated to the other. The LM hatch size was decreased, but the suit got bigger and no one realized this until the crews tried ingressing the vehicle on the Moon.

16. *An airlock may make ingress/egress easier and will also be a good idea from a dust control standpoint*. Designing an airlock to separate the vehicle hatch from the habitation area could decrease the risk of tracking lunar dust into the lunar module.

17. *Surface activities can begin once operationally feasible*. Crews generally felt a little “wobbly” upon stepping on the moon, but this was attributed to adapting to the EVA suit CG and the partial gravity rather than neurovestibular dysfunction. This statement had been reported in the literature[20] and needed to be explained to understand whether this would be a problem for lunar crews in the future. Coordination seemed to improve steadily during first couple of hours on the surface. The crews denied problems with spatial orientation on lunar landing. This was a concern operationally as experience with rotary wing pilots suggests spatial disorientation and conditions known as “brown out” have contributed to accidents. The commander and lunar module pilots reported similar conditions during landing operations on several missions[14] but denied the occurrence of spatial disorientation.

18. *There is no special training needed for 1/6g EVA's other than a familiarization session*. The astronauts stated the limited training they received using the Partial Gravity Simulator (POGO) and parabolic flight aircraft was sufficient for preparing them for lunar EVAs. Future lunar crews would do well to use this as lunar familiarization training but should not engage in elaborate partial gravity training devices or environments as the human body quickly adapts to the 1/6 g environment of the moon.

19. *Limit navigation into craters to < 20-26° slope*. Aside from the risk for injury on slopes greater than 20-26 °, the crews reported that they had to use a side-stepping approach to going up and down sloped terrain because of the limitations in suit mobility. This motion often placed the inertial mass of the suit and crewmember on one leg, which would tire after repetitive loading, either uphill or downhill. The slope of the terrain affected the ability to perform this motion and the crews estimated that 20-26° was the safe limit unassisted.

20. *Crews requested that an automatic position determination device be available to aid navigation on the lunar surface*. All sorts of ambiguities exist on the Moon, e.g. slopes, terrains, sun shadows, and bland environments. With the undulating terrain, it was very easy to lose known points of reference and geographic orientation despite being well versed in the two-dimensional topography. One lunar crewmember admitted to spending twenty minutes trying to re-orientate during the surface traverse. A navigation system available on the suit HUD and/or rover would be very helpful and save time during surface operations.

21. *Ladder rung height and width on the LM were good but the glove did not allow adequate grip for safety*. Crews were able to ascend and descend the LM ladder without difficulty and felt the rung height and width were easy to use. Their only concern was related to the inability to adequately grip the rung or side rails due to the limitations in the glove (see EVA suit section). Ladder height could be a concern if the glove issues are not addressed, especially if the crewmember is carrying equipment or an individual up the ladder.

22. *Ensure adequate water and food are available before and during lunar EVA*. Lunar EVA ranged from 3.5 to 7.5 hours. Total in-suit time for surface operations averaged 10 hours. Bear in mind that the LM atmosphere was similar to the CM at 5.0 psia and 100% O_2 therefore no EVA pre-breathe period was required. It is generally recommended that humans should drink 4-6 ounces of fluid for every 30 minutes of moderate exercise to maintain adequate hydration status[21]. The Apollo crews stated that they became thirsty and hungry during their LEVA and suggested making available adequate amounts of high-energy food and plain water.

23. *Lunar EVA should be performed as one continuous event*. The question was raised regarding LEVA and whether it should be broken down into two shorter duration events allowing the crew time to hydrate and replenish energy stores, etc. or as one continuous event. The astronauts' inputs overwhelmingly supported the later choice as the suit and vehicle prep time for LEVA take up an unreasonable amount of crew time.

24. *Risk factors for injuries identified.* The Apollo astronauts were queried about risky behaviors on the lunar surface or conditions that could predispose them to injuries. Overall, the crews felt the injury risk was low related to the partial gravity providing considerable time to react to a fall and the relatively short distance to fall considering their lunar weight was 1/6 their Earth weight. They were quick to mention that the videos of their falls on the Moon were misleading: it did not hurt to fall. However, the crews pointed out that their inertial mass did not change on the Moon. Given the EVA suit/PLSS (~194 lbs. on Earth) and crewmember mass and right set of circumstances listed below, sufficient energy could be applied to a joint or extremity to cause injury.

a) *Navigation into sloped terrain or craters > 20-26°.* A fall on sloped terrain may be well tolerated unless the crew was moving or carrying an external load, such as equipment or rock samples. Although the exact angle of the slope was an estimate, the crews remarked that stable footing was limited and leg fatigue would become more pronounced in terrain steeper than approximately 26°. Lack of suit mobility, primarily at the hips, compounded getting in and out of steep terrain. Another concern was the lack of peripheral vision in the suit and the inability to see where an outstretched hand might land. Hand or wrist injuries were more of a concern for some of the crewmembers than lower extremity injuries. The ability to estimate crater dimensions was compromised as mentioned by one crewmember in the following statement: "Reflective light in the shadows isn't as evident as on earth. Craters did appear steeper visually. We knew we had to go down into that crater, so it gave us concern."

b) *Rover activities*. The safety harness took roughly three minutes to fasten and some crews opted not to engage the buckle. The astronauts stated that the lunar module pilot in the right seat was at particular risk of falling out due to the undulating terrain and often being tilted downward and out the vehicle.

c) *Falling from a height*. Falling from the rim of a steep crater was a concern in some instances. Ladder height on the LM was less that six feet, but it became a concern with the poor glove grip mechanics. Mention of the proposed LSAM ladder height ranging from 20-28 feet drew sighs and obvious concern for injury.

25. ***To ensure operational success and optimize performance of the crews, allow adequate time to practice mission activities in a variety of environments including analogs that allow preparation for off-nominal events***. The Apollo astronauts used at least five different analog environments for training and testing equipment. The crewmembers stated that training in a lunar analog environment prepared them for actual lunar surface operations. They also indicated that this training gave them confidence under nominal circumstances that they would be well prepared for off-nominal events.

26. ***Plan the operations on the surface so that you protect the crews from themselves***. This recommendation relates to the earlier recommendation about protecting the crews from overwork and burnout. Adequate time is required for the lunar crews to have mental and physical rest during and between LEVA to prevent mistakes and reduce the risk of injury.

27. ***With extended ops on the moon, establish all the experiments in the first week***. Related to the previous recommendation, the Apollo crewmembers were sensitive to the fact that lunar surface operations are difficult and demanding work. Astronauts with longer surface-stay time would be more likely to make mistakes in procedures or handling equipment. Therefore, it would be good practice to deploy all the experiments and heavy load activity within the first week of a lunar stay to minimize error and injury risk.

28. ***A robot should perform routine, systematic, repetitive, menial tasks* (may help prevent repetitive use injuries)**. Physical tasks, such as surface drilling, moving equipment, and setting up experiments should be performed by automated systems to the extent possible to minimize repetitive use injuries and free up crewmember time on the surface. Examples of overuse injuries include medial or lateral epicondylitis in the elbow, DeQuervain's tenosynovitis at the wrist, and shoulder rotator cuff injuries. These overuse injuries have been reported in astronaut training[22]. Other overuse injuries seen in microgravity EVA include fingertip and fingernail trauma. Repetitive use also poses a risk of associated space suit wear and tear.

29. ***The Rover should have the ability to recharge your suit.*** The crews felt they could have performed longer LEVA but were limited to the consumables in the suit. A remote recharge station in the field or placed on the rover could potentially extend surface activity duration or be used in the event of a suit incident, such as a leak.

In-flight Illnesses

30. ***Low back pain should be treated with aggressive pre-mission and in-flight core strengthening program***. Some crewmembers have complained of significant low back pain (LBP). Low back pain was noticed early on in space flight by >70% of crewmembers. Symptoms are relieved by curving back into the fetal position. Aspirin and other analgesics provided little to no relief which has been a consistent finding throughout the space program[23]. Etiology is unclear but probably related to stretching of the fibers of the intervertebral disc's annulus fibrosis. Interestingly, the crewmembers denied exacerbations of LBP on lunar surface or return to 1g. The astronauts suggested developing a preflight exercise protocol to strengthen abdominal muscles. This recommendation is consistent with musculoskeletal expert recommendation that abdominal or "core" strengthening pre- and in-flight helps improve lumbar spine strength and stability and may prevent or lessen in-flight low back pain[24].

31. *Therapy to relieve muscle soreness, primarily in the forearms, must be available (improved glove design may assist this).* All the lunar astronauts suffered from some degree of forearm soreness during their surface activities. This soreness was related to repetitive grasping-releasing against resistance in the pressurized glove. Although the soreness improved overnight, this could result in overuse injury if the crew was subjected to consecutive LEVA. Therapy, such as non-steroidal anti-inflammatory medication, heat packs, and massage were offered as solutions by the crewmembers. The overall solution in their mind however was improving the glove design and adding mechanical assist with repetitive grasping-releasing motions.

32. *Constipation: improve the waste management collection system*. Constipation was related to diet (low residue), low fluid intake, and waste management problems. Individual crewmembers intentionally "constipated" themselves with Lomotil in order to reduce the frequency or prevent BM's. One CMP went the entire 6-day mission without a BM.

33. *Screen for CAD prior to selection for lunar missions*. The arrhythmia experienced during lunar EVA in one Apollo lunar crewmember was presumed to be related to hypokalemia (low serum potassium level) and dehydration on the lunar surface. This forced subsequent crews to take potassium supplements, which caused loose stools. This problem was compounded by a marginal waste management system. Underlying coronary artery disease (CAD) was the cause of arrhythmia in this crewmember found years later. Current CAD screening for ISS crewmembers is much more sensitive than the screening technology in the 1960s and should detect this condition in astronauts.

34. *A physician crewmember would increase the comfort level among the crewmembers and can be cross-trained to do other activities*. This was a consensus statement among the crewmembers regarding extended duration lunar operations. The Apollo crews had limited medical training and relied on input from the ground flight surgeon for medical issues (if they acknowledged that a medical issue occurred). A physician astronaut could be cross-trained to carry out mission related activities, as has been the experience during Skylab, STS, and NASA-Mir programs. One Apollo astronaut remarked, "Hell, if they can take a naval aviator and train him to do geology [on the Moon] they sure as hell can train a doctor to do useful things."

35. ***Adequate preventive measures and treatment for diarrhea must be available***. Another consensus statement by the crews was related to the bad experience using the Apollo waste management system. Unless this system is improved, loose or liquid stool contaminants in the cabin is very difficult to manage and clean. Fecal-oral contamination and infection also becomes an issue. Therefore, medications and/or dietary measures must be available to prevent its occurrence.

Medication/Medical Kits (Appendix D)

36. ***A card in the med kit to inform the crew of the medication duration, indication, and interaction with other meds is needed***. Confusion regarding use of medication, and more importantly, the duration of action occurred on several missions. This prevented crewmembers from using medications properly. One CDR remarked that he had forgotten how long Dexedrine lasted and suggested putting a card in the med kit to inform the crew of the medication duration, indication, and interaction with other meds. Crew felt they did not want to report any medication usage or other problems because of privacy concerns (private medical conference (PMC) was not available on the early Apollo missions). In addition to this recommendation, crew education by the flight surgeon was requested. It is important to note that current STS and ISS medical kits have this information readily available to the crews.

37. ***Add non-sedating antihistamines for allergy symptoms due to lunar dust exposure***. Symptoms related to lunar dust were described like allergies with runny nose, nasal congestion, and itchy, watery eyes. These symptoms gradually subsided with subsequent exposure during the short lunar stays. One Apollo astronaut recommended, "Adding a non-sedating antihistamine like Claritin® to the med kit might help." One of the Apollo flight surgeons related a story of moderately severe upper respiratory symptoms due to lunar dust exposure when he unstowed the suits after landing. These symptoms worsened with each subsequent exposure. He noted moderate elevations the total WBC count, primarily the eosinophil levels that are commonly associated with allergic reactions. It is important to note that he did not have pre-exposure baseline WBC counts done to document if the elevation was in fact due to the lunar dust exposure. Lunar dust however is not an allergen but a toxic irritant, so it is unlikely that an anti-histamine would work to ameliorate the upper respiratory symptoms. This area is currently under investigation by the Lunar Airborne Dust Toxicity Analysis Group (LADTAG).

38. ***Saline eye drops need to be available in large quantities*** **(however an eyewash will be available as part of the environmental health kit*)***. The lunar dust was ubiquitous in the vehicle cabin, and was very difficult to clear from the hands. Cabin fiberglass was also a problem on some of the missions. In each case ocular irritation occurred that required copious saline irrigation to treat. The crews felt that plenty of saline eye drops should be available in the med kit for both ocular and nasal toilet.

39. ***Provide items that are needed in daily life, e.g. nail clippers, lotions, Band-Aids, etc.*** **(Individual hygiene kit will be available)**. During medical debriefs, several crewmembers noted frustration at not having items used during the course of normal daily hygiene available in the on-board kits.

40. ***Sufficient analgesia to treat headaches***. Headaches were frequently reported during the missions. Crews were concerned that they may be due to elevated cabin CO_2 levels but the monitoring devices were unreliable. Headaches are one of the symptoms of Space Adaptation Syndrome (SAS)[20] and noted as one of the most frequently occurring symptom throughout the space program. Crews used acetaminophen or ibuprofen with improvement in symptoms. The recommendation was for a sufficient quantity to supply all astronauts for the duration of their mission.

41. ***Sleep medication must promote restful sleep but not be too sedating***. The sleep medication used during Apollo, Seconal, was a barbiturate. Side effects included excessive sedation and “hangover” effect, essentially drowsiness the day after a dose. Some lunar crews described sleep on the Moon as “two hours of nodding off” but were reluctant to take the sleep medication because of the sedation effect. The sleep medications, currently used by US astronauts on STS and ISS, are of a different drug class and generally much less sedating and promote restful sleep.

42. ***An adequate delivery system for nasal decongestants must be available for the crewmembers***. Nasal congestion was experienced by most crewmembers, and was attributed to the 100% O2 environment, dust, and viral exposures preflight. Actifed was used and provided moderate relief. Oxymetazoline (Afrin®), a topical decongestant, was unavailable for Apollo 7-13 due to packaging problems. Lunar crews stated that symptoms resolved on lunar surface after initial exposure to dust only to return when reentering the CM as the particulates floated in the cabin.

Environmental Impacts

43. ***Consider adapting the Skylab waste management system into the new vehicles***. In general, the Apollo waste management system worked satisfactorily from an engineering standpoint. However, throughout the medical debriefs the crews reported that the system required ~45 minutes from start to end for defecation. Crew had to strip off underwear requiring BIOMED sensors be removed which was a time consuming process. Application of the Apollo bag was often difficult. One Apollo astronaut described the process as “a complete mess” and “the only part of the whole mission that made me feel uncivilized.” Crews highly recommended creating a device that would allow them to assume a squatting position to have a BM. The Skylab charcoal system was good for waste management as it provided both the ability for the crew to strap down to the toilet assuming the squatting position and a ventilation system that controlled odor. However, off-nominal “output” such as loose stool or diarrhea is an issue not adequately addressed by either Apollo or Skylab systems. The urine collection system was “lousy” as the UCD frequently leaked. The crew was very concerned about voiding difficulties during critical operations. The urine bag, if used, created backpressure in the system, which contributed to one occurrence of in-flight urinary tract infection.

44. ***The sleep restraint system on the Apollo CM worked well and should be incorporated into the new vehicle design***. The straps used on the couches allowed the crewmembers to fasten securely within the sleeping bag. Some crewmembers found wedging themselves under the couches comfortable. The sleep system used in the LM was adequate, with a few members commenting that the hammock was very comfortable in 1/6 G, but other factors impaired restful sleep. One crewmember chose to sleep on the LM floor but found it very cold and dirty with lunar dust.

45. ***Sleeping bag needs to be large enough for crewmembers to get both knees to their chest***. The crewmembers often assumed this “fetal position” to treat low back pain and found it difficult, if not impossible, to bring both knees to their chest during sleep.

46. ***Thermal protective clothing or equipment should be available on board***. The Apollo 13 crews suffered hypothermia in the 39°F LM they used as a “lifeboat” during the contingency return. The EVA suits were available but they chose not wear them because of the difficulty stowing and unstowing items from storage compartments. The A13 CDR and LMP offered the recommendation that a simple, light, and effective thermal blanket should be available in contingency situations.

47. ***Drinking water should be available during sleep periods***. The CM and LM cabin was very dry prompting a frequent need to drink water, interrupting sleep. The astronauts suggested having a water bottle available next to the couch or in the sleeping bag.

48. ***Hot water capability for hygiene, beverage, and food preparation is essential***. The astronauts felt very strongly that having the capability to heat water for routine daily dietary and hygiene use was a necessity. Cold water would be nice to have, but hot water required, a position they felt was not negotiable.

49. ***Apollo bag aperture and capacity needs to be larger and easier to apply in microgravity***. The Apollo bag was a bag that crew members passed stool into. Crews unanimously stated that the Apollo bag aperture was too small and the application was very difficult in microgravity. A better system has to be developed for future crews.

50. ***Create a device that would allow crewmembers to assume a squatting position in microgravity***. The crews summed it up well with this statement: "Try pooping standing up with a bag stuck to your butt and see how you like it." Engineers will have to do a better job in the waste management design on future vehicles.

51. ***Do not design the galley and waste management areas together***. The reason for this recommendation should be obvious but the Apollo galley and waste management area were designed within a foot of each other. The crews frequently had diminished appetites for other reasons and did not need the added effect of odor and mess to further compromise their nutritional intake.

52. ***Minimize noise but do not eliminate it* (earplugs are an adequate countermeasure for noise)**. Noise was an issue for sleep, especially on the LM, but was comforting to the crew. Non-essential communications from MCC were annoying and need to be eliminated during the sleep period. Simple ear plugs work well and more elaborate systems are not necessary. As an aside, in the LM sunlight was blocked with shades to aid in restful sleep.

53. ***Carbon dioxide* (CO_2) *monitoring device needs to be robust and reliable***. The CO_2 monitor was frequently malfunctioning with resultant unreliable sensor readings. Crews often remarked they had headaches during the missions, one of the initial symptoms associated with elevated CO_2 levels. The faulty sensor system made it difficult to attribute the crew's symptoms to elevated CO_2 levels in the cabin. This problem persists today on the STS and ISS with crews frequently reporting headaches.

54. ***A food warmer is desirable***.

55. ***Astronaut participation in the design and development phases of the new vehicles is essential***. The Apollo astronauts were intimately involved with the requirement development phase through vehicle assembly. Many attributed their mission success to this knowledge of the vehicle systems and hardware. Astronauts associated with the new vehicles should be involved with all phases of its development.

56. ***RFID tags should be considered for stowage items***. Radio-frequency identification (RFID) systems are well established in organizing stowage and retrieval of equipment and other mission gear. This system would provide a reliable tool to locate items within the stowage compartments of the new vehicles and track consumables usage.

57. ***LSAM windows should be designed to see only what is necessary for landing and/or rendezvous with IR protection***. Windows are heavy components of the vehicle and should be designed with these requirements to minimize their mass. Crews will require adequate protection from IR radiation exposure.

58. ***Design an efficient method for clearing the lunar dust from the vehicle cabin***. Lunar dust particles floated everywhere in the LM upon return to microgravity. Dust particles got into crewmembers eyes, nose, and chest, which prompted the Apollo 12 crew to keep their helmets on prior to docking with CSM. The dust did not appear to be filtered from the environment through ventilation/LiOH system although the vacuum cleaner that was used beginning with Apollo 14 seemed to help clear the larger particles.

Radiation

59. ***The lunar excursion vehicle should have an active radiation detector with an automated audible alarm that sounds when the dose rate exceeds a predetermined level***. The Apollo mission plan for a radiation event on the lunar surface was based on incorrect assumptions. The assumption was that after Earth-orbiting satellites detected the initial x-rays, the crews had between 15-20 hours before the solar protons arrived at the Moon[25]. During this time the crews would be directed to make the traverse back across the lunar terrain from the worksite to the LM, prepare the vehicle and launch off the surface, successfully rendezvous with the CM, dock and secure the hatch, transfer to the CM, and rotate the vehicle so that the thicker side of the vehicle faced the sun thereby absorbing the radiation. Apollo crews did not have an active radiation detection and alarm system with them on the lunar surface. Recently, a solar event occurred where energetic protons arrived at Earth within 5-20 minutes of the original x-ray detection. (Note: We also have more information about the directionality of solar protons and this suggests crews should not launch from the lunar surface during a solar particle event.) Obviously, the Apollo response requires reconsideration. The crews were adamant that the lunar return crews have the capability to detect hazardous radiation levels. The EVA suit, rover, and habitat should have the capability to provide autonomous detection and immediate response countermeasures should be embedded in these systems.

60. ***A personal radiation dosimeter (PRD) is a requirement for all crewmembers***. Although this was a requirement for all crewmembers, some of the Apollo crewmembers neglected to wear the device in the suit during lunar surface operations. They recommended designing it into the suit garments thereby eliminating the possibility that it would be left behind.

61. ***The rover should be equipped with a radiation shield***. A durable and effective shield for solar protons should be available for crews on the lunar vehicle for a solar particle event.

62. ***Radiation protectants should be made available to the crewmembers***. Recent developments in radioprotectants suggest that they may be useful to mitigate the risk of developing radiation sickness in crews exposed to solar radiation. The Apollo astronauts stated that they would consider using such compounds if exposed to radiation while on the lunar surface.

63. ***Create a trench with shovels or explosives to protect the crew short term in the event of a solar particle event* (SPE)**. For radiation protection on the surface, creating a trench with shovels or explosives would be adequate to protect the crew short term. It is important to cover the trench quickly with regolith. A real-time active PRD in the suit will let you know how well you have done with regards to exposure and when it would be safe to leave the site. In-suit consumable recharge capability would have to be available.

Performance/Human Factors

64. ***Recreational activities need to be made available for crews during trans lunar coast (*TLC) *and trans Earth coast* (TEC)**. Trans-lunar and Trans-Earth coast were relatively "*boring,*" however, this was an individual experience. Crew wish they had brought recreation materials. Apollo Command Module Pilots (CMP) remarked that the CDR/LMP could relax but he was always on task during this [TLC/TEC] mission phase. Crewmembers reported that they liked having the non-work related time during TLC and TEC, but wanted recreational activities available during this time. Exercise was one of the most desirable activities during this mission phase. This was also important for the CMP during lunar surface operations. Apollo crews recommended for long-duration missions "*make the space vehicle environment as normal as it is down on Earth.*" The CEV should be as autonomous as possible. Several of the CMP's stated that it was difficult at times to stay focused during lunar surface operations. Air-to-ground communications helped tremendously. MSFN relay was the best thing CMP had during this time. Other activities included watching the local news to make the day more similar to Earth. Delegation of routine operational "chores" and flight plan maintenance to the MCC would free the CMP to do non-work related activities, such as lunar or deep space photography. The A15 CMP stated he used this time to explore deep space while on the far side of the moon (shielded from the sun). He later claimed to have discovered black holes as a result of his uninterrupted time in the CM.

65. ***Mental and physical rest plans should be introduced into extended moon stays to allow adequate rest between lunar EVA***. "*Consider mental and physical fatigue here separately. Although there was not a lot of physical fatigue* [during the lunar activity]*, the mind was being used quite a bit. You can sometimes wear your brain out before your body is fatigued*."

66. *Mission focus should be project-oriented and not timelined*. The Apollo lunar surface crews lamented that the timeline on the Moon was very ambitious leaving little room for completing tasks in the event things did not go as planned. Future timelines should not be rushed and should allow crews to complete projects thereby minimizing error and potential injuries. A non-EVA suit related injury did occur during one mission that was a result of the astronaut trying to complete a timelined activity with a malfunctioning piece of equipment. The injury required the crewmember to use a rather excessive amount of analgesics for pain.

67. *Use of sleeping medication should be encouraged where appropriate*. The crews were generally reluctant to use sleep medication because of the side effects previously described. "*There was always the fear of not being alert if an emergency came up-this can't work for long duration stays*." A number of astronauts also felt that use of sleep medication would be perceived among their peers and ground controllers as a sign of weakness.

68. *Countermeasures to combat mental fatigue are necessary throughout the mission*. Mental fatigue pre-launch was due to the amount of non-essential training [that was not operationally oriented]. There was too much "just-in-time" before launch emergency procedure training. They suggested more "normal procedure" training and less emergency procedures training. Additionally, they suggested slowing the pace of training within 1-2 weeks prior to launch. They all launched fatigued. Preflight quarantine is very valuable as it allows time for simulation training, exercise, and rest. The crew schedule should have "*slack early in the mission to allow time for learning/training*."

69. *Education and psychological services should be available to the crewmembers' families*. NASA should be more sensitive to the families needs than they were during Apollo. Family counseling was rejected by NASA when the crewmembers requested it.

70. *Allow adequate time in the schedule for all activities*. In designing future mission scenarios, the following are recommendations for optimizing operational success and crew health: allow adequate time to practice mission activities in a variety of environments where tasks are defined and duplicated just like on the moon; allow time for all activities such as eating, resting, exercise, experiments, etc. This will take coordination with the mission planners, and is especially important to allow enough time for meals. However, the astronauts were quick to point out that during certain mission phases, such as rendezvous and docking, adequate time may not be available for these activities.

71. ***Provide adequate capabilities for sleeping on the lunar surface***. Refer to the environmental section. The lunar crewmembers cited three environmental factors that impaired their ability to get restful sleep: light penetration into the vehicle, loud ambient noise level, and cool cabin temperature (particularly near the floor of the LM). Planners for the LSAM and future lunar habitat will have to correct these factors in addition to the aforementioned requirement for short-acting, well-tolerated sleep medication that does not cause excessive sedation or hangover effect. In addition, the sleep facilities will have to take into account the factors mentioned in the environmental section. In addition, the EVA suit did not provide comfortable sleep on the lunar surface. The inability to get restful sleep on the moon [because of the suit] "could have jeopardized the mission."

72*. If a crewmember dies during the mission "cut him loose."* Death of a crewmember during a mission is straightforward: "*If a crewmember dies, you cut him loose. You can depressurize the hatch and dump him*." "*Yes, if it happens, it happens…No psycho babble here*." The crews emphasized that trying to retain or recover a deceased astronaut could put the other crewmembers at risk. This plan would require working out the details far in advance of the mission so that all individuals involved, including the astronaut family members, would be prepared in the event this happened during a mission.

73. ***In planning crew size/makeup, the authority structure is much more significant than crew size***. This recommendation arose out of questions pertaining to the makeup of future exploration crews with regard to number of crewmembers, male/female ratios, etc. The Apollo astronauts were unified in their recommendation to emphasize that crew make-up requirements are secondary to the crew authority structure, i.e. the commander is in charge under all circumstances. The Apollo astronauts were military trained and understood authority structure, and this was never more evident than during Apollo 13. The crew supported their commander and insured that he was given whatever was necessary to make the correct decisions during the mission rather than trying to usurp his authority over concerns he might be succumbing to fatigue or stress. Bottom line with crew size/makeup is to make sure they understand who is in charge. The other issues are of less importance.

74. ***Consider the impact on the mission control flight teams and take actions to ensure that they are rested and provided for during the lunar missions***. The crewmembers were sensitive to the demands made on the flight control teams and their families that resulted from planning and carrying out a lunar mission. They urge that NASA take necessary steps to support these individuals and their families during all phases of the mission. This included allowing enough time for sleep, family time, and training prior to and during the mission. The impact of the workload of mission control support personnel is a factor. In addition, they need defined sleep periods and time off to keep the mission functioning.

Crew Schedule

75. ***Preflight quarantine is very valuable for providing time for mission simulation, exercise, and rest***. From an operational point of view, it removed a large number of distractions from the last three weeks of preparations and the crews were much more rested for launch.

76. ***The preflight training schedule should allow crews to concentrate on issues that will be used for the nominal mission***. The crews wanted only mission related activities, such as simulator training and safety briefings, to occupy their time during the month prior to launch. Activities outside of training, such as exercise and rest, were often compromised during this time and should be as high a priority as any other training issue.

77. ***Lunar crews should have one day/week for "rest"* (freedom to select their activity)**. During the lunar surface stay, crews should have a scheduled day of rest during each seven-day period. This day would not have timelined activities but could be used at the crew's discretion. The Apollo astronauts emphasized that for extended duration operations, the crew will burn out if they do not have protected rest time during the week.

78. ***An eight hour per day sleep period must be protected in the daily schedule and must not be compromised***. Crew rest time was often the subject of compromise in the daily timeline, as it is today. However, the crew strongly encouraged the flight surgeons to protect the sleep period regardless of whether the crew actually slept. Circadian rhythm was considered not to have been an issue on lunar expeditions. Regarding sleep shifting, it was not optimum to have large shifts in short periods of time. Also, the Schumann Resonance Frequency (SRF) must be considered. Crews suggested discussions with experts to evaluate the risk factor influencing sleep cycles once the crew is out of the Earth's geomagnetosphere.

79. ***Crews should be scheduled for simultaneous sleep periods.*** The initial Apollo missions had staggered crew sleep periods but were later changed to accommodate all crewmembers. This practice should be continued with the lunar return missions.

Exercise

80. ***Loosen the pre-mission timeline to allow adequate time for preflight conditioning program***.

81. ***A more robust (and lightweight) piece of in-flight exercise equipment is needed than the Apollo Exer-Genie***. This device was the only exercise equipment available during the Apollo missions and was used by all crewmembers with varying amounts and intensities. A major limitation in the

Exer-Genie use was the friability of the ropes that connected to the cylinder that provided resistance and the heat that was generated with its use. The Apollo CM atmosphere was 100% O_2 and there was a real concern that the heat generated represented a fire hazard. The crews used the device at sub-maximal levels to reduce heat generation. One crewmember stated that the rope and material "*frays and kinda smells*" after prolonged use.

82. *The flight surgeon/mission planners should not plan specific exercise prescriptions for short duration* (< 14 days) *mission*. The crews performed exercise for rest and relaxation purposes as much as for the physical benefit. They cautioned the flight surgeons against trying to timeline specific exercises. They felt the crews should be instructed on what exercise would be beneficial and applicable for the device available, choosing what they wanted to do during short duration missions.

83. *Exercise is not necessary on short trips* (14 days or less) [from a fitness standpoint], *however crews demanded that the capability be available and varied as much as possible for crew "rest and relaxation" in all phases of the mission*. The crews did not feel that they suffered noticeable deconditioning during their relatively short missions. They do not dispute the science that shows muscle and bone strength decrements with longer microgravity exposures, however. In the context of their short missions and lunar EVAs, they were able to perform all mission related activities without concern from loss of strength or stamina. However, the astronauts demanded exercise capability for the CM for rest and relaxation purposes. A couple of crewmembers also experienced minor Achilles tendonitis after return to Earth and suggested that a more aggressive lower extremity stretching program enroute to home may have prevented this occurrence. The lunar surface crews felt that their activities on the Moon provided enough exercise for a short duration mission but would have welcomed a simple, robust device for stretching and forearm strengthening exercise.

84. *Develop a better preflight and in-flight forearm muscle-conditioning program for lunar crewmembers*. In addition to the core stabilization program as described earlier in the illness/injury section, a strengthening program for the forearm muscles before and during the mission is necessary. Upper extremity exercises, specifically to strengthen and maintain shoulder strength and stamina, will be necessary in the preflight period and during the mission. Operating the surface tools in partial gravity, particularly the drill, requires more force generated from the shoulders than needed in 1 g.

85. *New vehicle design should allow a variety of different exercise capabilities* (hardware vs. cabin structure). Recommended examining the new spacecraft design to determine surfaces or structures within the vehicle to exercise various muscle groups. A more robust (and lightweight) piece of equipment is needed. The Crews performed isotonic exercises against the struts of the LM on the surface before EVA's. Another example of using the vehicle in novel ways to perform exercise included “running in place holding onto the couch,” isometrics performed against cabin structures, etc.

86. *Put as many* [exercise] *capabilities in the vehicle as possible, because it will get used*. Many crewmembers felt exercise capability throughout flight will be critical. A variety of exercises must be provided.

87. *New exercise devices should be reliable, simple, and not develop excessive heat in use*. The crew was concerned towards the end of the mission that they were going to “break the machine” and began tapering down the exercise duration and intensity to protect the equipment so that it would be available for reconditioning prior to re-entry.

Food/ Nutrition

88. *Mission activity* (e.g. coast, rendezvous, lunar orbit, lunar OPS, etc.) *will dictate what type and how much food will be consumed*. Apollo diets offered 2100-2660 kcal/day, but the crews seldom obtained these required energy intakes. During busy mission phases, the crews often went without eating or drinking because of issues with preparing food or problems associated with the water system. They recommended that meal planners work with mission planners to coordinate easily accessible food that could be prepared quickly to ensure that crew energy needs are met throughout all mission phases. Specific examples of mission activity and appropriate food types include:

- High activity – wet packages, bite-sized snacks, canned foods
- Low activity – spoon-bowls, dry juice or meals (rehydratable) requiring mixing etc.

89. *Plain water in large quantities needs to be available for lunar EVA*. The crewmembers stated that they needed more plain water available for LEVA. As was mentioned in the EVA suit and Lunar Surface Operations section, the lunar crews often went 10 hours without a break after suiting up.

90. *Optimize diet and food intake for overall performance during long duration missions*.

91. *An in-suit non-caffeinated solid or liquid carbohydrate food source for lunar EVA would be helpful*.

92. *Design adequate space and useful area in the new vehicles to store food packs during meals*. Lack of available space and useful area to store food packs during meals made eating difficult. Food preparers need to be mindful of the difficulties associated with performing tasks in microgravity.

93. *Spicy and salty foods are preferred items in the menu*. Overall, the food lacked flavor or spice. Crews preferred the salty bite-sized snacks or other flavorful items as their taste perception changed in space compared to the preflight food testing.

94. ***Allow adequate time in the daily schedule for meals***. Refer to comments in recommendation # 88.

95. ***Determine how different environmental factors* (e.g. O2 concentration, cabin pressure) *effect food flavor***. Foods tested preflight tasted fine but were "absolutely unattractive in-flight." One crewmember who had flown both an Apollo and STS mission stated he had a poor experience with food during Apollo but the same food flown on Shuttle was palatable and tasty. His experience raised the question of the effect of the 5.0 psia and 100% O_2 atmosphere of Apollo on food integrity or taste perception compared to the 14.7 psia and 21% O_2 of the Space Shuttle. The future vehicles have a proposed cabin atmosphere of 7.6-8.0 psia at 30-32% O_2.

Launch, Landing and Recovery Ops

96. ***Provide adequate cooling capabilities for the crew on landing to mitigate the hot cabin contribution to crewmember seasickness***. Considerable weight loss was attributed to sweating and dehydration that occurred on landing secondary to seasickness. Inadequate cabin/suit cooling after landing was cited as the primary contributor to both conditions. The future landing vehicle must have adequate cooling capabilities for the crews. The onset and severity of seasickness will be determined by the crew's ability to stay cool more than anything else.

97. ***Ground landings are discouraged***. This was not a consensus statement among the crewmembers. A number of the Apollo astronauts were adamant that a ground landing would likely kill the crewmembers. NASA has considerable experience with water landing, have never lost a crew by landing in the sea, and have a much larger margin of error for re-entry. Ground landings do not afford much error and may pose a threat to humans in populated areas with an off-trajectory re-entry profile. The dissenting Apollo astronauts, however, mentioned that we now have extensive experience via the shuttle with ground landings, and that perhaps water landings could be used to build confidence before moving forward with ground landings.

98. ***Apollo seat configuration for water landings was adequate***. The seats were adequate for re-entry despite force distributed throughout body. Impact was well distributed across the back. Couches and restraints were adequate for landing and launching from the Earth and Moon in terms of side and head protection. All loose items need to be restrained; one crewmember sustained a scalp laceration after being struck in the head by an object that came loose when the capsule impacted the water.

99. ***Medication for motion sickness and fatigue will be available prior to re-entry***. Scopolamine 0.3mg/Dexedrine 5mg were taken by several crewmembers prior to re-entry and again at splashdown to prevent motion sickness (MS) and to combat fatigue.

100. ***Sea state should be limited to < 6-8 foot swells if recovery is to be delayed***. Most of the Apollo astronauts were naval aviators or experienced pilots with one exception. Nearly all the astronauts experienced seasickness, some reporting the onset of symptoms within 30-60 seconds of the water landing. The crews strongly recommended that the recovery sea state be limited to less than 6-8 foot seas.

101. ***Have food and plain water within reach of buckled crewmembers for delayed recovery***. Dehydration was a significant concern due to lack of suit or cabin cooling. Food and plain water will need to be readily available for the crews in sufficient amounts to sustain the crew until recovery teams can remove crew from the landing capsule.

102. ***Apollo CM hatch location and size was adequate for egress***. Hatch location for landing egress was ok. Apollo crewmembers denied having any trouble emerging from the capsule after landing. The crews offered a mixed response as to whether they would have been able to assist an injured crewmember in an emergency scenario. Crewmembers also recommended that the hatch on the re-entry vehicle open outward. A hatch design that opens outward but does not seal with pressure is very dangerous.

103. ***All control panels and switches should be within reach of crewmembers during launch and landing***. Regarding the control panels and switches, all required functions were within reach during high g and zero g in the Apollo CM. This was tested in centrifuge runs in the design and development phase. The same approach should be taken for the new launch and return vehicle.

104. ***Training for pad abort was adequate and should be continued***. The slide wire abort works. One crewmember felt the egress route under the pad room in Apollo provided a faster and safer escape route than the slide wire.

105. ***Crew surgeon should be on the recovery vessel and not the helicopter***. The rescue crew provides all the necessary skills for safely transferring the crew from the vehicle to the helicopter. The crew flight surgeon serves his/her purpose best on the recovery ship and should not be put at risk in the recovery aircraft.

Flight Surgeon-Crew Interaction

106. ***Crews encouraged the Flight Surgeon to "act as more of an advocate of the crew" than treat them as an experiment***. Crews often felt the flight surgeon treated them as "*an experiment*" considering the demands the flight plan placed on them. Lack of PMC with flight surgeon limited the crew input regarding physiological functions and medication usage during flight. After one CMP was left hanging regarding his flight status due to an abnormal lab value 3 weeks prior to launch, the CDR and CMP both felt the flight surgeon was not looking out for the crew's "mental well being." The CDR emphasized that "emotional stress is one of the main issues [that surgeon] needs to help minimize both preflight and in-flight for his/her crew."

107. ***The collaboration established between the current flight surgeons and Apollo crewmembers should continue and be an example to future generations***.

Discussion

The purpose of this study was to identify Apollo operational issues that impacted crew health and performance. The specific goals of this project were to develop or modify medical requirements for new vehicles and habitats, to create a centralized database for future access, and to share relevant Apollo information with the multitude of entities at NASA and abroad participating in the exploration effort. Secondary objectives included using this information to validate current requirements and refresh knowledge regarding lunar operations. The database has been created to complete this study, and the information gleaned is currently being shared among NASA entities. What remains is to discuss the modification of exploration medical requirements based on the experiences of the Apollo astronauts.

The only sentient experience that the human race has with manned lunar exploration is through the perceptions and memories of the 22 surviving Apollo astronauts. As such, their experience and knowledge is a vast resource that has been surprisingly untapped in the ways in which this paper has attempted to extract. One of the reasons for this is the "cradle-to-grave" operational focus of the study. Underlying everything from the abstract to the conclusion was the ethos of "operationally driven outcomes". In other words, the focus was to determine how the positive and negative experiences of the Apollo astronauts can improve the mission operations of the Constellation crews. The authors diligently focused on extracting that which had potential operational relevance, so that the varied audience could come away from the paper with something tangible to incorporate into their exploration work. Also, as discussed in the Methods section, previous published data was exhaustively researched to pre-empt duplication of results and conclusions. Further, data contained within this paper has been reviewed for accuracy by the Apollo astronauts. Hence, the results are an attempt at achieving untainted representations of the thoughts and recommendations of the Apollo astronauts themselves. Up to this point the authors of the paper have just been the “middle-men”.

Therein lays both the strength and limitation of the ability of the Results to “develop or modify medical requirements for new vehicles and habitats”. Are these events and challenges that occurred over 35 years ago applicable today? On Apollo missions, the astronauts were allowed to bring one cassette tape into space for morale purposes. Today astronauts can carry an Ipod® with 80 Gigabytes and 20,000 songs. True, there are now new paradigms and new technologies, however, the authors feel that those who don’t learn from history are bound to repeat it. Just as Sun Tzu’s “Art of War” is as true and applicable today as it was in the 6th century B.C., the lessons of the Apollo astronauts can find significance and relevance with future exploration missions. Limitations inherent in this study do, however, include non-response bias and the volunteer effect, procedure bias, and recall bias. Also, although there are limitations to the applicability of the 107 recommendations, some recommendations are “more relevant” than others. For example, there were many recommendations regarding the waste management system. Many of these issues have been vastly improved through years of shuttle and space station experience. These recommendations are somewhat “less relevant”. However, in general, the recommendations in the categories of EMU/EVA Suit Operations, Lunar Surface Operations, and Lunar Radiation are “more relevant” due to the fact that they are related more closely to Lunar exploration and have not yet been duplicated or improved upon. In the end, the relevance of each recommendation must be considered carefully and individually.

The principle findings of this study can be broken down into broad pervasive themes and themes relevant to each of the 11 recommendation categories. Three themes were ubiquitous throughout the study. The first two, safety and mission accomplishment, were explicit and self-evident. These two ideas are intertwined, virtually impossible to separate, and at the core of every recommendation that was put forth. The third ever-present, but almost “unconscious” theme was one of human factors, and in particular, the idea that “the astronauts are only human”. When analyzing the raw data and results one gets the idea that the astronauts are imploring the establishment to acknowledge that they are humans, not robots, test subjects, or infallible beings. This was evident with multiple recommendations spanning the 11 categories. For example, scheduling-related recommendations were made in 4 of the categories for a total of 23 recommendations. Likewise, sleep-related recommendations were made in 3 categories with 10 recommendations, and more generally, allocations for “rest and relaxation” were mentioned in 6 categories with ~26 recommendations. Further evidence of the astronauts’ recognition of their limitations includes multiple recommendations for ensuring adequate “self-maintenance” via exercise, nutrition and fluid intake, and a higher level of waste and personal hygiene. Finally, the astronauts made multiple recommendations (7 in 6 categories) and requests regarding Flight Surgeon/Physician advocacy and intervention. Military pilots traditionally have had an apprehensive relationship with Flight Surgeons; hence the astronauts' appeal to seek assistance from someone who could potentially ground them should carry some weight. They even went so far as to unanimously recommend the addition of a physician-astronaut as a crewmember, with the thought being that a physician-astronaut would increase the comfort level among the crew, and could serve as a strong advocate for astronaut needs while in space. A final observation worth mentioning is that the astronauts' recommendations were very difficult to categorize. That is, a single recommendation such as "Improve glove flexibility, dexterity, fit", simultaneously involves operations, engineering, human factors, safety, and mission accomplishment. This brought to the forefront the uniquely interdisciplinary nature of manned space exploration and the broad appeal of this paper.

The tables following each category show the 107 recommendations followed by the current status and disposition of that recommendation. The status definitions are as follows:

In Practice	the recommendation is operational in current shuttle and ISS missions
New Requirement	the listed requirement was created as a direct result of the Apollo recommendations
Requirement Modified	the listed requirement was revised as a result of the Apollo recommendations
Requirement Validated	the listed requirement was validated by the Apollo recommendations
Being Evaluated	the recommendation is actively being analyzed for future requirements
Consider	the recommendation is known by involved parties, but there is no formal review for acceptance or rejection
Rejected	the recommendation has been evaluated and subsequently rejected as a requirement

The emphasis of the recommendations varied through each of the 11 categories:
EMU/EVA ISSUES

Recommendations centered first and foremost on improving the functionality of the suit then improving both the human factors integration as well as specific safety features. The most adamant of the suit recommendations and a consensus statement was to improve the dexterity of the glove. This recommendation had mission accomplishment and safety as the driving concerns. Similarly, the astronauts recommended increasing ambulatory and functional capability through increased suit flexibility and decreased mass and internal pressure. This would have the added benefit of decreasing fatigue as well. The astronauts' human factors recommendations revolved around consumables and excretion. They recommended in-suit access to large amounts of high energy liquids and plain water, a Heads-up Display with consumable, biomedical, and navigation information on demand, and an improved urinary collection system. Safety concerns revolved around redundancy being built into the suit. In particular, they suggested a system to prevent helmet fogging under all circumstances, a self-sealing pressure garment in case of puncture, and a system to protect the zipper from abrasive lunar dust.

Spacesuit technology has improved over the years through shuttle and ISS experience, however, only the Apollo astronauts have the experience of operating under 1/6 G in the lunar environment. As such, their insight is very relevant to exploration requirements.

As can be seen in the table below, the EVA Systems Project (ESP) and the Human Research Program (HRP) via the EVA Physiology Systems and Performance (EPSP) element is quite active with this set of Apollo recommendations. The EPSP and ESP is aggressively evaluating multiple recommendations and considering several others. EPSP has a systematic test plan that will address all of the suit related issues and result in specific data backed recommendations for the optimal suit weight, mass, pressure, center of gravity, and kinematics (mobility) for lunar operations. Additionally, the EPSP and Exploration Medical Capability (ExMC) team have addressed the UCD issues and have developed improvements to the Maximum Absorbant Garment (MAG).

Table 3: EMU/EVA ISSUES Recommendation Implementation

EMU/EVA ISSUES						
Cat	**#**		**Apollo Recommendation Summary**	**Status**	**Disposition**	**Reference**
Functionality	1		Improve glove flexibility, dexterity, fit			
		a)	Gloves should be custom designed for each crewmember that incorporate mechanical closure for gripping	Being Evaluated	Being Evaluated for Cx CP, suit D&C document (level 3) Eval per ESP/EPSP	
				In Practice	Already in practice for flight gloves	
		b)	Look into a wrist seal and depressurized glove	Consider	Will consider with counter pressure suit concept	
		c)	Robotic power-assisted glove for repetitive tasks	Consider	Will consider in design for planetary suit configuration	
		d)	Glove liners should be worn	Requirement Validated	Already in practice, to be continued in Cx D&C	
	2		Reduce the mass of the suit by a factor of two	Being Evaluated	Suit mass trades being evaluated by ESP/EPSP and suit engineers	
	3		Increase general mobility by a factor of four, primarily at the knee joint	Consider	Suit mobility requirements being defined by ESP/EPSP	

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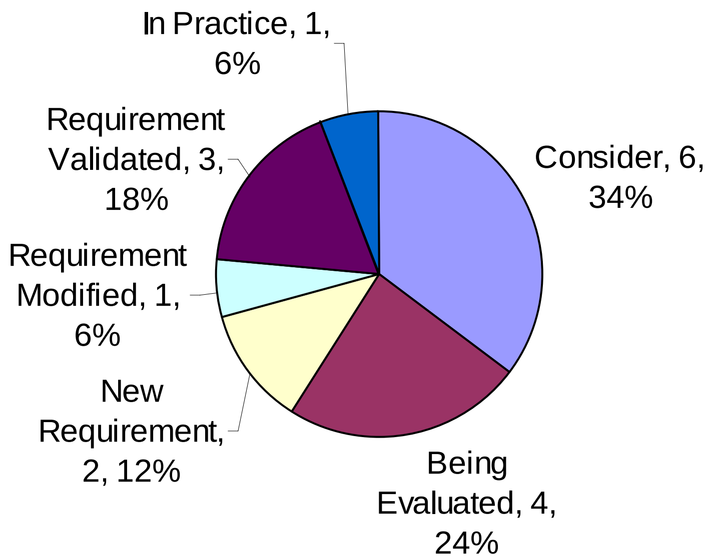
	4		Lower suit Center of Gravity	Being Evaluated	C.G. trades being evaluated by ESP/EPSP	
	6		Improve peripheral vision by adding neck ring (movable joint)	Being Evaluated	Trade between mobility vs. potential for landing injury due to a hard ring, evaluation by ESP/EPSP; requirement TBD in D&C document	
	8		The lunar boot functioned well and does not need to be improved.	Requirement Validated	Boot requirements in D&C Suit trauma eval per EPSP	
	12		The suit should be a low pressure (3.50 psia), single gas system	New Requirement	Requirement in HSIR- variable pressure suit 3.5-8.0 psi; 100% O2; Suit pressure trades being evaluated by EPSP	3.5.5.2.2
Human Factors	7		Develop a reliable Heads Up Display that shows consumables information, limited biomedical data, and navigation on demand	New Requirement	Display requirement in HSIR for planetary suit. Implementation TBD for HUD vs. voice activated being evaluated by ESP/EPSP	3.6.4.1
	10		The drink bag should have capability to contain a high energy liquid in addition to plain water	Requirement Modified	Requirement in HSIR for planetary suit	3.5.1.4.1
	11		Develop a better in-suit Urine Collection Device (UCD) that will work in 1/6 g	Requirement Validated	Requirement in HSIR, spec's for MAG will include improved interface. Additional details in Level 4 suit documents TBD, being evaluated by ExMC and ESP/EPSP	3.5.2
Safety	5		Develop a system that prevents helmet fogging during heavy exertion	Consider	Consider Helmet ventilation specified in D&C to prevent fogging; being evaluated by ESP/EPSP	
	9		Use a self-sealing pressure garment within the suit for puncture	Consider	Consider HSIR requirement for DCS risk reduction Materials selection in D&C and level 4 suit specs; being evaluated by suit engineers and ESP/EPSP	
	13		Protect the suit zipper function	Consider	Consider in D&C specs and level 4 suit specs	

EMU/EVA ISSUES



LUNAR SURFACE OPERATIONS

These recommendations revolve around human factors, safety, and operational efficiency. Human factors and safety considerations were particularly intertwined in this category. A recurrent theme on the lunar surface was an overwhelmingly packed schedule. For extended operations, the astronauts were adamant about decreasing the workload in the schedule. They suggested a maximum of 2 LEVAs within a 3 day period and a schedule with flexibility and "breathing room" built into it. They also felt that surface operations can begin once operationally feasible, that LEVAs should be one continuous event with ample food and liquids available before and during the event, and that the schedule should be front-loaded early on to minimize error and injury. Major risks identified were falls, rover operations, and navigating slopes in excess of 20-26°. With suit functionality improvement, some of the risks identified will be reduced. To increase operational efficiency the astronauts recommended using HUD technology, robots for repetitive tasks, and the rover to recharge suits. They also felt that for extended operations, LSAM ingress and egress portals must be closely scrutinized. They emphasized with a consensus statement that the hatch size must comfortably accommodate pressurized suits and that engineers consider an airlock. In general, they felt that the familiarization training with 1/6 G and analog training was sufficient.

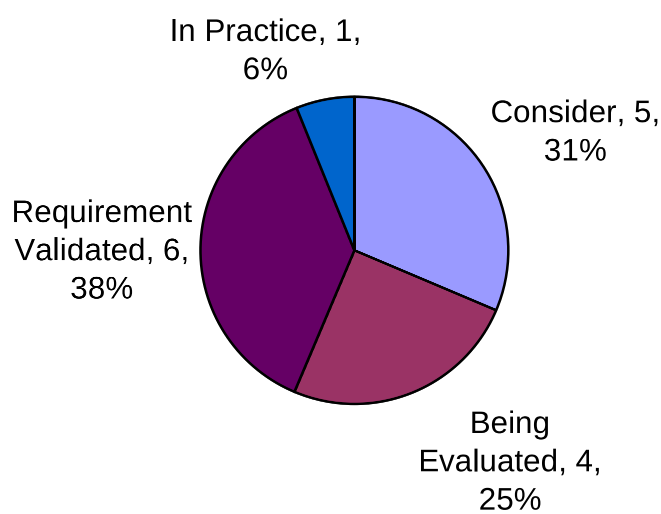
This category in particular is very relevant to lunar exploration missions. While 3 days was the longest any of the astronauts spent on the moon, many of their recommendations inferred problem areas for extended lunar stays. Also many of their recommendations are straight forward and difficult to counter. For example, guarding against overwork and ensuring food and water availability seems obvious once it is mentioned, but may not be so clear in planning phases. Surprising recommendations included the astronauts' acknowledgement and requests for new technology that one might have thought to be outside of the paradigms of these mostly 1960s and 70s era astronauts. Also, multiple recommendations have already been implemented by virtue of Shuttle and ISS operations.

Table 4: LUNAR SURFACE OPERATIONS Recommendation Implementation

LUNAR SURFACE OPERATIONS						
Cat	**#**		**Apollo Recommendation Summary**	**Status**	**Disposition**	**Reference**
Human Factors	14		Schedule crews for two Lunar EVA days on and one day for maintenance, alternating crews throughout the week	Being Evaluated	LAT2 and ARDIG defining architecture; to be placed in Ops Con document	
	16		An airlock may make ingress/egress easier and will also be a good idea from a dust control standpoint	Requirement Validated	Requirement for Airlock in EARD and CARD; NESC/LADTAG advocating suitlock engineering solution for dust mngt.	
	22		Ensure adequate water and food are available before and during lunar EVA	Requirement Validated	Requirement in HSIR	4.5.1.4
	26		Plan the operations on the surface so that you protect the crews from themselves	Consider	Will need Ground and Flight Rules to limit	
	28		A robot should perform routine, systematic, repetitive, menial tasks (may help prevent repetitive use injuries).	Consider	LAT2 surface focus element, ARDIG and EVA systems to consider	
Safety	17		Surface activities can begin once operationally feasible	Requirement Validated	Ops Con includes surface tasks for crew during landing day	
	19		Limit navigation into craters to < 20 - 26º slope	Being Evaluated	ARDIG/Ops Con consideration; will need a Flight Rule, evaluated at planetary analog HMP 2006	
	21		Ladder rung height and width on the Lunar Module (LM) were good but the glove did not allow adequate grip for safety	Requirement Validated	Revised handhold requirements in HSIR	
	23		Lunar EVA should be performed as one continuous event	Requirement Validated	Ops Con, EVA Con Ops (level 3)	
	24		Risk factors for injuries identified:	Consider	Consider at the level 3&4 SRDs and Flight Rules; being evaluated by ESP/EPSP and ECP	
		a)	Navigation into sloped terrain or craters > 20 - 26º			

		b)	Rover activities: CDR, LMP at risk for injury if not restrained			
		c)	Falling from a height. The rim of a crater, the ladder			
Operations	15		The hatch and ingress corridor should be sized appropriately for an inflated 1/6 g pressure suit	Requirement Validated	Validated but under threat of rejection, weight push backs are driving the hatch size closer and closer to absolute minimums; for LSAM ingress/egress must be easy; minimal hatch req's being evaluated by ESP/EPSP	
	18		There is no special training needed for 1/6 g EVA's other than a familiarization session.	Consider	Lunar Crew Operations Training Plan, may use POGO or similar 1/6 G simulator- EPSP evaluating	
	20		Crews requested that an automatic position determination device be available to aid navigation on the lunar surface	Being Evaluated	EPSP evaluating navigation and position aids for surface EVA; consider for EVA system requirements document	
	25		To ensure operational success and optimize performance of the crews, allow adequate time to practice mission activities in a variety of environments including analogs that allow preparation for off-nominal events	In Practice	Planetary exploration Analog WS to be held in March, analog management by HQ and ARDIG	
	27		With extended ops on the moon, establish all the experiments in the first week.	Consider	Will need Ground Rules and put Expedition planning guidelines	
	29		The Rover should have the ability to recharge the suit	Being Evaluated	LAT2 Surface Ops Focus Element evaluating EVA Ops trades	

LUNAR SURFACE OPERATIONS



INFLIGHT ILLNESSES

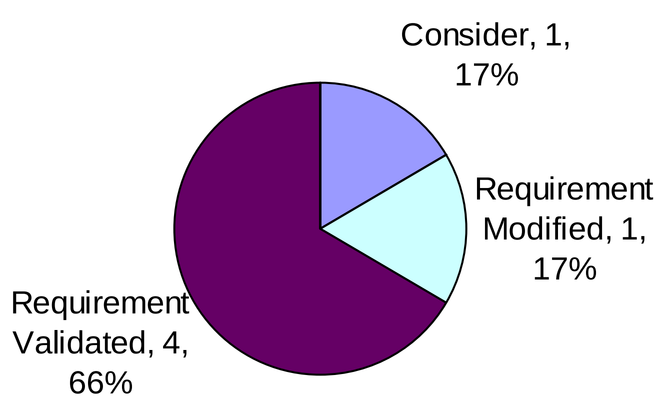
This category reflected human factors issues of pain, GI dysfunction, and preventative screening. In particular, treatments or preventative measures were sought for lower back and forearm pain and soreness, constipation and diarrhea, and heart disease. The two consensus statements in this category included therapy to relieve muscle soreness, especially in the forearms, and to include a physician crewmember to increase the comfort level among the crewmembers. This category also demonstrated the inter-disciplinary nature of space operations. For example, it was discovered that crewmembers intentionally constipated themselves with medications to reduce or completely prevent bowel movements. On further questioning it was found that a contributing reason for this was the poor waste management collection system. Another example is the forearm soreness. With a better designed glove, this complaint is no longer an issue.

This category although significant, has less relevance due to Skylab, Shuttle, and ISS operations with similar issues Table 3 shows that all issues except the consensus related statement regarding a physician-astronaut are accounted for.

Table 5: IN-FLIGHT ILLNESS Recommendation Implementation

IN-FLIGHT ILLNESS						
Cat	#		Apollo Recommendation Summary	Status	Disposition	Reference
Human Factors	30		Lower back pain should be treated with aggressive pre-mission and in-flight core strengthening program	Requirement Validated	Cx MORD	
	31		Therapy to relieve muscle soreness, primarily in the forearms, must be available (improved glove design may assist this)	Requirement Validated	Cx Medical Kit contents definition	
	32		Constipation: improve the waste management collection system	Requirement Modified	Requirement for waste management in HSIR	3.5.3, 4.5.3
	33		Screen for CAD prior to selection for lunar missions	Requirement Validated	SFHSD medical standards now required for long duration flight	
	35		Adequate preventive measures and treatment for diarrhea must be available	Requirement Validated	Level of Care in HSIR, Cx Medical Kit contents definition TBD	3.5.5.5.5
Operation s	34		A physician crewmember would increase the comfort level among the crewmembers and can be cross-trained to do other activities	Consider	Consider development of Crew selection guidelines for Lunar Outpost	

IN-FLIGHT ILLNESS



MEDICATION/MEDICAL KITS

Recommendations focused on medications that would have improved operational efficiency and comfort. Kit contents requested included allergy medications, saline eye drops, standard toiletries (nail clippers, lotions, etc.), headache analgesia, efficacious sleep medications, and an efficient decongestant delivery system. All of these are currently accounted for or improved upon (i.e. including an eyewash in addition to saline drops) in the Constellation requirements.

Table 6: MEDICATION/MEDICAL KITS Recommendation Implementation

MEDICATION/MEDICAL KITS						
Cat	**#**		**Apollo Recommendation Summary**	**Status**	**Disposition**	**Reference**
Contents	36		A card in the medical kit to inform the crew of the medication duration, indication, and interaction with other meds is needed	Requirement Validated	HSIR Level of Care requirement, but details in Cx Medical Kit contents definition TBD, this will be based on Delphi patient care database	3.5.5.5.5
	37		Add non-sedating antihistamines for allergy symptoms due to lunar dust exposure	Requirement Validated	Cx Medical Kit contents definition TBD	
	38		Saline eye drops need to be available in large quantities (however an eyewash will be available as part of the environmental health kit)	Requirement Validated	Cx Medical Kit contents definition TBD	
	39		Provide items that are needed in daily life, e.g. nail clippers, lotions, band-aids, etc. (individual hygiene kit will be available)	Requirement Validated	Flight Crew Equipment contents definition, currently included in long duration flight crew kits for ISS	
	40		Sufficient analgesia to treat headaches	Requirement Validated	Cx Medical Kit contents definition TBD	
	41		Sleep medication must promote restful sleep but not be too sedating	Requirement Validated	Cx Medical Kit contents definition TBD	
	42		An adequate delivery system for nasal decongestants must be available for the crewmembers	Requirement Validated	Cx Medical Kit contents definition TBD	

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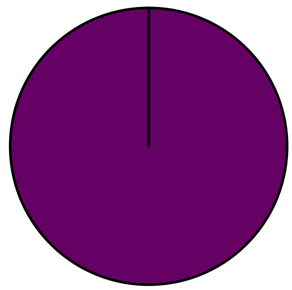
MEDICATION/MEDICAL KITS



ENVIRONMENTAL IMPACTS

Human factors and operational design were the two foci of the Environmental Impacts recommendations. Within human factors, recommendations dealt with waste management, sleep, and consumables. The astronauts unanimously recommended the adaptation of the Skylab waste management system. They also wanted to see a device to allow for squatting for bowel movements, felt that the Apollo bag aperture and capacity both needed increasing, and would prefer that the galley and waste areas be separated. To foster restful sleep, the astronauts recommended minimizing environmental noise, having water available during sleep, increasing the sleeping bag size to allow for the “fetal position”, and the incorporation of the CM sleep restraint system. Hot water capability was deemed essential and non-negotiable via a consensus statement. A food warmer was also considered desirable. Operational concerns centered on engineering redesign, a contingency input, and increasing efficiency. First and foremost, the crewmembers consensus was that astronaut participation in design and development is essential. Another consensus statement was to incorporate more reliable CO_2 monitors. They also felt that the LSAM windows should be as small as possible and that there should be a system for clearing lunar dust from the cabin. A consensus statement born of Apollo 13 was to include thermal protective gear in the event of a contingency. The last recommendation was to utilize RFID tags for stowage items.

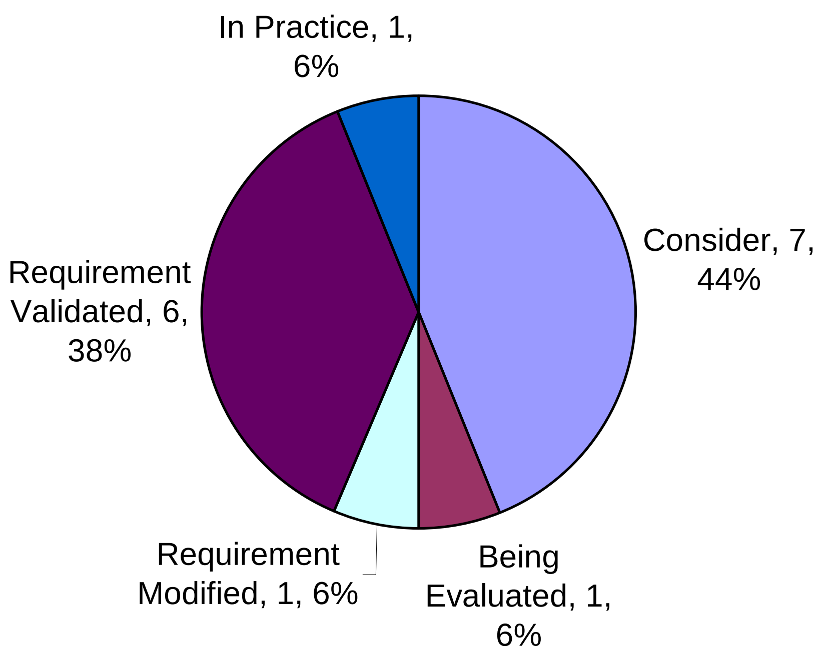
The recommendations brought to light some points that would have been missed just as they were during Apollo. For example, as a result of the recommendations thermal protection is being added to the crew equipment. Other changes and additions are shown in Table 5.

Table 7: ENVIRONMENTAL IMPACTS Recommendation Implementation

ENVIRONMENTAL IMPACTS						
Cat	**#**		**Apollo Recommendation Summary**	**Status**	**Disposition**	**Reference**
Human Factors	43		Consider adapting the Skylab waste management system into the new vehicles	Requirement Modified	Requirement for waste management in HSIR	3.5.3, 4.5.3
	44		The sleep restraint system on the Apollo CM worked well and should be incorporated into the new vehicle design	Consider	Requirement for sleep accommodations in HSIR, details for Level 4 document TBD	3.5.5.6
	45		Sleeping bag needs to be large enough for crewmembers to get both knees to their chest	Consider	Requirement for sleep in HSIR, details for sleeping bag at Level 4 document TBD	3.5.5.6.1
	47		Portable drinking water should be available during sleep periods	Consider	Requirement for potable availability at all times in HSIR, the details for the portability of water will be in a Level 4 document	4.2.2.2
	48		Hot water capability for hygiene, beverage and food preparation is essential	Requirement Validated	Requirement in HSIR	3.2.2.3.2
	49		Apollo bag aperture and capacity needs to be larger and easier to apply in microgravity	Consider	Contingency waste collection requirement in HSIR- details will be defined in Cx level 5 spec document	3.5.3, 4.5.3
	50		Create a device that would allow crewmembers to assume a squatting position in microgravity	Requirement Validated	Requirement in HSIR for WCS use restraints	3.4.3.3
	51		Do not design the galley and waste management areas together	Requirement Validated	Requirement for separation of galley and WCS in HSIR	3.5.1.1.1
	52		Minimize noise but do not eliminate it (earplugs are an adequate countermeasure for noise)	Requirement Validated	Acoustics requirements in HSIR	3.2.6.1
	54		A food warmer is desirable	Requirement Validated	Requirement in HSIR	3.5.1.2.1
Operations/Engineering	46		Thermal protective clothing or equipment should be available on board	Consider	Level 4, Flight Crew Equipment contents definition	
	53		CO2 monitoring device needs to be robust and reliable	Requirement Validated	Requirement in HSIR	3.2.1.4.1
	55		Astronaut participation in the design and development phases of the new vehicles is essential	In Practice	Currently in practice for Cx for each vehicle and requirements definition.	
	56		Radio Frequency ID tags should be considered for stowage items	Consider	Consider for CxP level 4 and 5 documents- design solutions for stowage tracking	

	57		Lunar Surface Ascent Module (LSAM) windows should be designed to see only what is necessary for landing and/or rendezvous with IR protection	Being Evaluated	Requirement in HSIR for non-ionizing radiation exposure, consider for LSAM window spec Level 5 document	3.2.8.3
	58		Design an efficient method for clearing the lunar dust from the vehicle cabin	Consider	HSIR has lunar dust exposure limit. Consider for LSAM requirements document	3.2.1.6.4

ENVIRONMENTAL IMPACTS



RADIATION

Apollo astronauts were concerned about radiation detection and contingency plans. They felt that all vehicles, habitats, and suits should have radiation detectors and dosimeters built into them. They also felt that the rover should contain a radiation shield, they should have the ability to create trenches for solar particle events, and that pharmacological radiation protectants should be made available.

Thanks to Skylab, the shuttle, and the ISS, there is a large body of operational knowledge regarding radiation in LEO; however, radiation on the surface of the moon is a different entity. The astronauts were clearly concerned about radiation, and more research needs to be done in this area.

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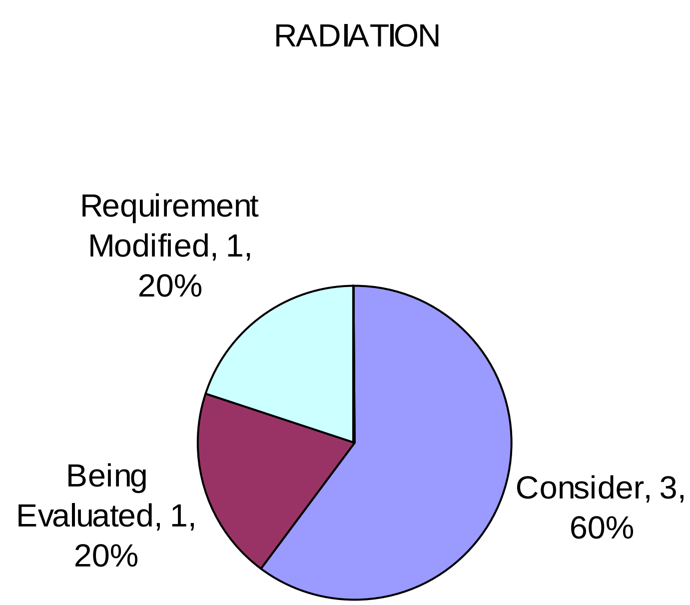
Table 8: RADIATION Recommendation Implementation

RADIATION						
Cat	**#**		**Apollo Recommendation Summary**	**Status**	**Disposition**	**Reference**
Detection	59		The lunar excursion vehicle should have an active radiation detector with an automated audible alarm that sounds when the dose rate exceeds a predetermined level	Requirement Modified	Requirement in HSIR, recently revised under review for EVA; req. being developed by ExMC and NSBRI	3.5.5.1.5
	60		A Personal Radiation Dosimeter is a requirement for all crewmembers and should be designed into suit garments	Consider	Requirement in HSIR; Need also in EVA system and suit requirements document	3.2.7
Contingency	61		The rover should be equipped with a radiation shield	Consider	Consider for rover requirements document and ARDIG Level 2; being evaluated by LAT2 surface element	
	62		Radiation protectants should be made available to the crewmembers	Being Evaluated	Cx Medical Kit contents definition TBD - research not well funded at present; some eval by ExMC and EPSP	
	63		Create a trench with shovels or explosives to protect the crew short term in the event of a Solar Particle Event	Consider	Consider for radiation protection Con Ops; alternate strategies being evaluated, analogue/HMP 2007 test item not funded	



PERFORMANCE/HUMAN FACTORS/CREW SCHEDULE

This category generated many recommendations. They can be broken down into mental (and physical) health concerns and operational concerns. The mental health recommendations dealt with R&R time, sleep, and psychological preparation. R&R consensus statements called for 1 day per week for astronaut discretionary use and the implementation of mental and physical rest plans. Some astronauts also requested recreational activities to be available during down time. Interestingly, the astronauts also displayed empathy and concern for the workload of the mission control teams in the form of a recommendation. Regarding sleep, the astronauts felt that the crew sleep periods should be concurrent, that adequate capability for sleep on the lunar surface should be provided, and that sleep medication use should not be stigmatized. They also unanimously agreed that a minimum of 8 hours per day of sleep and rest must be protected. Regarding psychological preparation and well-being, the astronauts unanimously agreed that educational and psychological services must be available to their families and that if a crewmember dies during the mission, all involved must be prepared to “cut them loose”.

Operational concerns overwhelmingly focused on scheduling issues. Crews felt that the preflight quarantine was very valuable and that the preflight training schedule must allow the crew time to focus on the mission. They also felt that throughout the mission including preflight, countermeasures for mental fatigue are necessary and that adequate time for activities must always be provided. They also recommended that the mission focus be project-oriented and not time-lined. The final recommendation emphasized the importance of the crew authority structure over all other concerns of crew resource management or crew composition.

Table 9: PERFORMANCE/HUMAN FACTORS Recommendation Implementation

PERFORMANCE/HUMAN FACTORS						
Cat	**#**		**Apollo Recommendation Summary**	**Status**	**Disposition**	**Reference**
Mental/Physical Health	64		Recreational activities need to be made available for crews during Trans Lunar Coast and Trans Earth Coast. CMP during lunar surface operations.	Requirement Validated	Private audio and video requirement in HSIR, recreational elements under BHP in Cx MORD	3.5.5.1.1 and .2
	65		Mental and physical rest plans should be introduced into extended moon stays to allow adequate rest between lunar EVA	Consider	Cx Medical kit definition	
	67		Use of sleeping medication should be encouraged where appropriate	Requirement Validated	Cx MORD and Cx Med Kit definition TBD	
	69		Education and psychological services should be available to the crewmember's families	Requirement Validated	BHP Requirements in Cx MORD	
	71		Provide adequate capabilities for sleeping on the lunar surface	Consider	Details for sleep station in LSAM in Level 3 and 4 documents	

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	72		If a crewmember dies during the mission you cut him/her loose	Being Evaluated	Med Code 0 management and NASA policy under definition Cx MORD and Ops Con	
	74		Consider the impact on the mission control flight teams and take actions to ensure that they are rested and provided for during the lunar missions	Consider	Consider for GRnC and MCC handbook - TBD	
Operations	66		Mission focus should be project-oriented and not timelined	Consider	Need to capture this philosophy in Ops Con for lunar outpost missions and GRnC TBD	
	68		Countermeasures to combat mental fatigue are necessary throughout the mission	Requirement Validated	Cx Medical kit definition TBD	
	70		Allow adequate time in the schedule for all activities	Consider	Need GRnC entry for this - TBD	
	73		In planning crew size/makeup, the authority structure is much more significant than crew size	Consider	Consider development of Crew selection guideline	

PERFORMANCE/HUMAN FACTORS

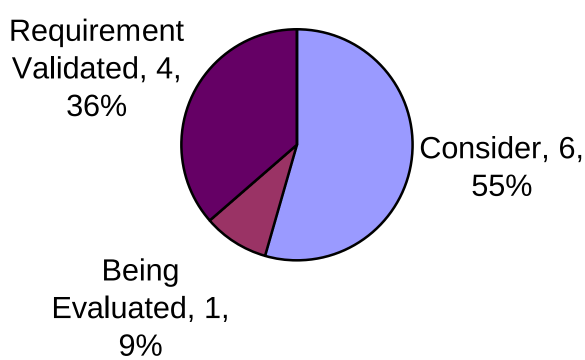
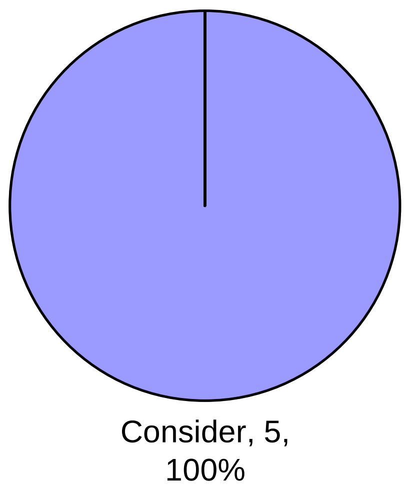


Table 10: CREW SCHEDULE Recommendation Implementation

CREW SCHEDULE						
Cat	**#**		**Apollo Recommendation Summary**	**Status**	**Disposition**	**Reference**
Operations	75		Preflight quarantine is very valuable because it allows time for simulators, exercise and rest.	Consider	Need to be built into GRnC and crew training plan; CxMORD has preflight quarantine requirement already	
	76		The pre-flight training schedule should allow for crews to concentrate on issues that will be used for the nominal mission	Consider	Consider for crew training plan	

Mental/Physical Health	77		Lunar crews should have one day a week for "rest" (freedom to select their activity)	Consider	Need GRnC entry for this	
	78		An eight hour/day sleep period must be protected in the daily schedule and must not be compromised	Consider	Need GRnC entry for this	
	79		Crew sleep periods should be scheduled at the same time	Consider	Need GRnC entry for this	

CREW SCHEDULE



EXERCISE

Recommendations regarding exercise centered on scheduling concerns and the exercise equipment. While they felt that exercise isn't required on trips < 14 days from a strength/endurance perspective and that exercise prescriptions for short trips were likewise not necessary, they unanimously felt that the availability must exist to exercise for R&R during all phases of the mission. They felt exercise is required for longer duration lunar missions. They also felt that scheduling needs to allocate time for preflight conditioning and that a preflight and in-flight forearm conditioning program be included. The Exer-Genie on Apollo missions was considered sub-par, and the astronauts unanimously felt that new exercise devices should be reliable, simple, and safe. They also encouraged that as much exercise variety is built into the vehicle and equipment as possible.

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Table 11: EXERCISE Recommendation Implementation

EXERCISE						
Cat	**#**		**Apollo Recommendation Summary**	**Status**	**Disposition**	**Reference**
Operations-Scheduling	80		Loosen the pre-mission timeline to allow adequate time for pre-flight conditioning program	Consider	Need to be built into GRnC and crew training plan; CxMORD has preflight conditioning as does the Space Flight Health Document	
	82		The flight surgeon/mission planners should not plan specific exercise prescriptions for short duration (< 14 days) mission	Being Evaluated	Not consistent with SA position (we say < 8 days).; HSIR requirement for exercise for all missions > 8 days.	3.5.4.1.1
	83		Exercise is not necessary on short trips (14 days or less) [from a fitness standpoint], however crews demanded that the capability be available and varied as much as possible for crew "rest and relaxation" in all phases of the mission	Requirement Modified	Not completely consistent with current requirement; HSIR requirement to begin exercise as soon as practical	3.5.4.1.1
	84		Develop a better pre-flight and in-flight forearm muscle conditioning program for lunar crewmembers	Requirement Modified	CxMORD preflight conditioning; ASCR pre-flight prep document to be revised from current ISS document for exploration missions. Strength/endurance requirements for mission tasks being developed by ECP	
Engineering-Equipment	81		A more robust (and lightweight) piece of in-flight exercise equipment is needed than the Apollo Exer-Genie	Requirement Validated	Requirement in HSIR; Need h/w spec definition at level 4 and 5 under evaluation by ECP	3.5.4.1.1
	85		New vehicle design should allow a variety of different exercise capabilities (hardware vs. cabin structure)	Requirement Modified	Requirement in HSIR; need outpost exercise requirements in Level 3 Lunar Outpost Requirements	3.5.4.1.1
	86		Put as many [exercise] capabilities in the vehicle as possible, because it will get used	Consider	Need outpost exercise guidelines in Level 3 Outpost Requirements; Lunar Habitat Team earmarking exercise area in habitat. H/w under eval by ECP	
	87		New exercise device should be reliable, simple and not develop excessive heat in use	Requirement Modified	Requirement in HSIR; Need h/w spec definition at level 4 and 5, being evaluated by ECP	3.5.4.2.1

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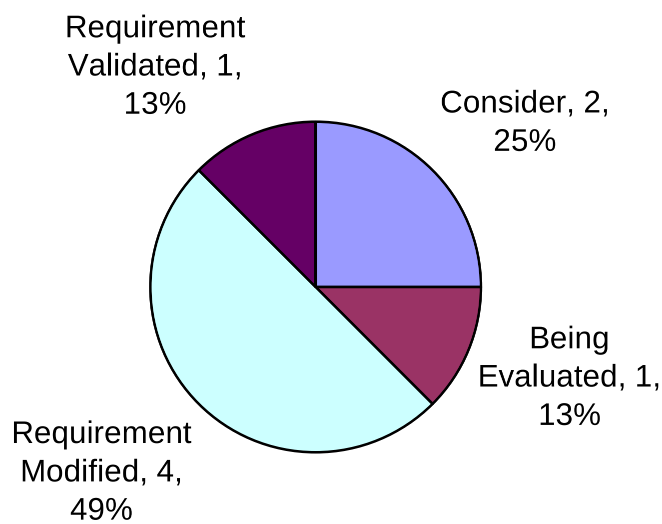
EXERCISE



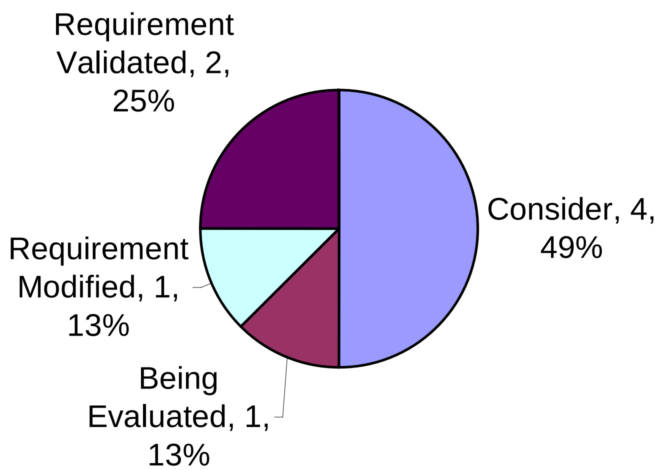
FOOD/NUTRITION

This category resulted in a surprising number of recommendations. The astronauts commented on nutritional requirements, taste preferences, logistics, and operations. The astronauts unanimously agreed that mission activity dictates the type and amount of food that will be consumed. They also were unanimous in recommending ample water availability for LEVAs and felt that an in suit source of carbohydrates would be helpful. They felt that for long duration missions diet and food intake would need to be carefully optimized. Regarding food flavor they preferred spicy and salty foods and suggested research into how different environmental factors affect food flavor. They unanimously agreed that ops needs to schedule adequate time for food and also would like to see the new vehicle allocate space and areas to store food packs during meals.

Table 12: FOOD/NUTRITION Recommendation Implementation

FOOD/NUTRITION						
Cat	**#**		**Apollo Recommendation Summary**	**Status**	**Disposition**	**Reference**
Requirements	88		Mission activity (e.g. coast, rendezvous, lunar orbit, lunar ops) will dictate what type and how much food will be consumed. High Activity: wet packages, bite-sized snacks, canned foods Low Activity: spoon bowls, dry juice or meals (rehydratable) requiring mixing, etc.	Requirement Modified	Nutrition requirements in HSIR; CxMORD; Need food system requirements at level 4 and 5	3.5.1.3.1 3.5.1.3.2
	89		Plain water in large quantities needs to be available for lunar EVA	Requirement Validated	Requirement in HSIR	3.2.2.2.1
	90		Optimize diet and food intake for overall performance during long duration missions	Requirement Validated	Requirement in HSIR	3.5.1.3.1 3.5.1.3.2
	91		An in-suit non-caffeinated solid or liquid carbohydrate food source for lunar EVA would be helpful.	Being Evaluated	Under evaluation by EPSP and ExMC	
Engineering	92		Design adequate space an useful area in the new vehicles to store food packs during meals	Consider	Stowage requirement in HSIR, Level 4 requirements needed for food system details being evaluated by Food Science Lab	3.5.6
Palate	93		Spicy and salty foods are preferred items in the menu	Consider	Food system requirement at level 4 and 5	
	95		Determine how different environmental factors (e.g. O2 concentration, cabin pressure) effect food flavor	Consider	Need research topic for HRP	
Ops	94		Allow adequate time in the daily schedule for meals	Consider	Need GRnC entry for this	

FOOD/NUTRITION



LAUNCH, LANDING, AND RECOVERY OPS

This category could be broken down into discussions regarding a sea recovery, operations, and engineering ergonomic concerns. Many of the astronauts discouraged ground landings and felt that cooling capability on landing was required to mitigate sea sickness. They also felt that food and water must be within reach of buckled crew members for delayed recoveries. Additionally, they stated that the Apollo seats were adequate for water landings and the medications for motion sickness and fatigue should be available prior to re-entry. Operationally, they wanted to see a flight rule to limit sea state landings to <6-8 foot swells if recovery is to be delayed. They also felt that the crew surgeon best fulfills his duty from the recovery vessel not the helicopter. Training for pad aborts were thought to be adequate. Regarding engineering ergonomics the astronauts felt that the CM hatch location and size were adequate and that all switches and panels should be reachable during launch and landing.

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Table 13: LAUNCH, LANDING, AND RECOVERY OPS Recommendation Implementation

LAUNCH, LANDING, AND RECOVERY OPS						
Cat	**#**		**Apollo Recommendation Summary**	**Status**	**Disposition**	**Reference**
Sea Recovery	96		Provide adequate cooling capabilities for the crew on landing to mitigate the hot cabin contribution to crewmember sea sickness	Being Evaluated	Cabin environment requirement in HSIR; 36 hr post-landing tiger team working details of ECLSS, suit, etc. need CR to CEV SRD	3.2.3.1.2
	97		Ground landings discouraged	Being Evaluated	Land vs. water tiger team weighing trades	
	98		Apollo seat configuration for water landings were adequate: the restraint system needs to include loose equipment items	Requirement Validated	Seat requirements in HSIR; CEV SRD (previously in crew cockpit document)	3.4.2.6; 3.3.2.3
	99		Medication for motion sickness and fatigue will be available prior to re-entry	Requirement Validated	CxMORD; Medical Ops Con and Crew Medication Kit definition TBD	
Operations	100		Sea state should be limited to < 6-8 foot swells if recovery is to be delayed	Consider	CEV SRD defines sea state for vehicle; Ground Ops con defines recovery strategy	
	104		Training for pad abort was adequate and should be continued	Consider	Need to include in crew training plan	
	105		Crew surgeon should be on the recovery vessel and not the helicopter	Requirement Modified	Ops Con, Cx MORD, and Med Ops Con	
Engineering	101		Have food and plain water within reach of buckled crewmembers for delayed recovery	Consider	Need to add requirement to HSIR and CEV SRD and 36 hour post-survival Tiger Team	
	102	a)	Apollo Command Module hatch location and size was adequate for egress	Requirement Validated	Hatch requirements in HSIR, vehicle specific hatch dimension in SRD	3.4.4
		b)	Hatch should open outward and seal with pressure	Consider	Hatch requirements in HSIR Level 3 and 4 requirements for hatch operation details TBD	3.4.4
	103		All control panels and switches should be within reach of crewmembers during launch and landing	Requirement Validated	Cockpit requirements in HSIR; CEV SRD and Crew Cockpit document	3.6.3.2.2

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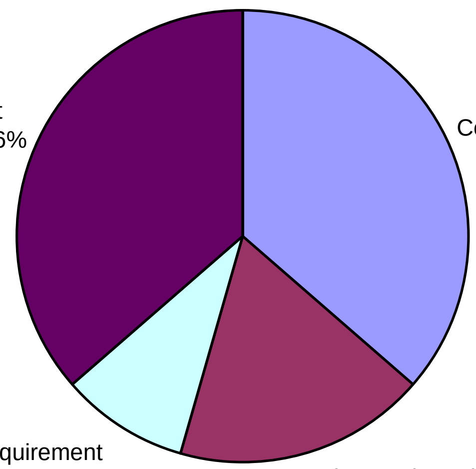
LAUNCH, LANDING, AND RECOVERY OPS



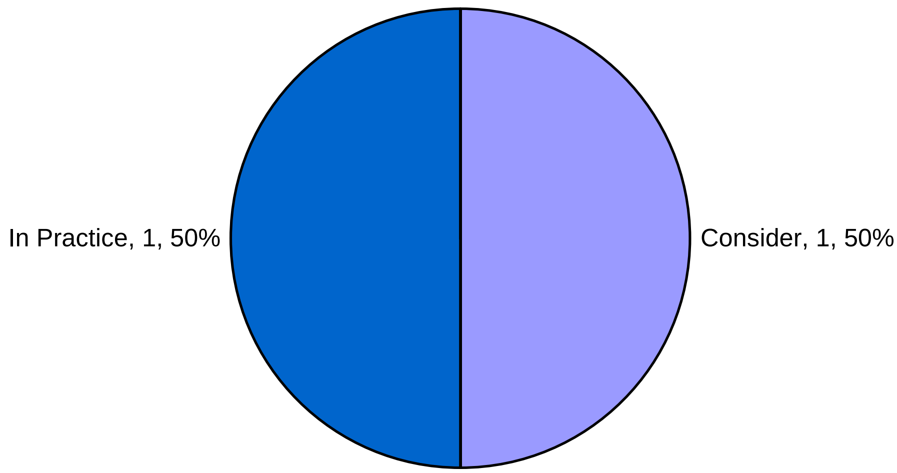
FLIGHT SURGEON-CREW INTERACTION

The crews felt that the Flight Surgeon must act as an advocate for the crew and that the collaboration born of this study between the Flight Surgeons and the Apollo astronauts should continue and be an example to future generations.

Table 14: FLIGHT SURGEON-CREW INTERACTION Recommendation Implementation

FLIGHT SURGEON-CREW INTERACTION						
Cat	**#**		**Apollo Recommendation Summary**	**Status**	**Disposition**	**Reference**
Resource Management	106		Crew encouraged FS to "act as more of an advocate of the crew" than treat them as an experiment	In Practice	Currently in practice	
	107		The collaboration established between the current flight surgeons and Apollo crewmembers should continue and be an example to future generations	Consider	Roger and concur	

FLIGHT SURGEON-CREW INTERACTION

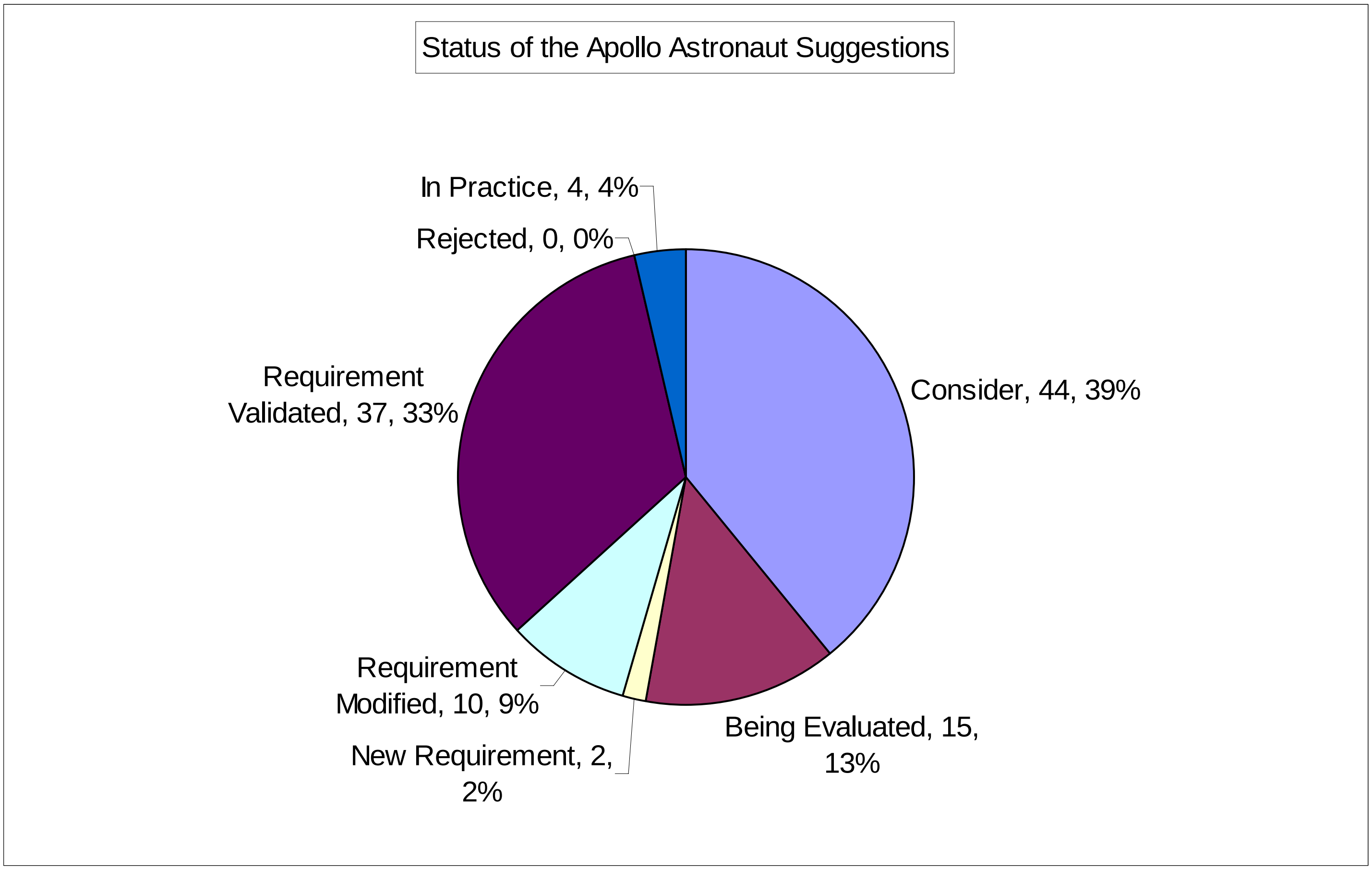


In summary, we see that the 107 recommendations break down as follows:

Category	Number of Recommendations	Percentage
Consider	44	39%
Being Evaluated	15	13%
New Requirement	2	2%
Requirement Modified	10	9%
Requirement Validated	37	33%
Rejected	0	0%
In Practice	4	4%
Totals:	112	100%

Note that a few recommendations that the Apollo astronauts made were broken down into multiple recommendations and hence there was 112 resultant data points analyzed as opposed to 107. In the table we see that 48% of the recommendations validated, revised, or created new requirements or are currently in practice, and 52% are being considered or evaluated. Of this 52%, there is potential for requirements being further modified, validated, or created. Hence, we see that many of the experiences of the Apollo Astronauts have been considered relevant, and have impacted the exploration architecture.

Figure 2: Overall status of the Apollo suggestions



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Conclusion

The Apollo Medical Operations Project was undertaken to identify Apollo mission issues relevant to medical operations that had an impact on crew health and/or performance. The goals of this project were to develop or modify medical requirements for new vehicles and habitats, create a centralized database for future access, and share relevant Apollo information with the various entities at NASA and abroad participating in the exploration effort. Secondary objectives included using this information to validate current requirements and refresh knowledge regarding lunar operations.

The theme of the Apollo astronaut's 107 recommendations is *res ipsa loquitur* or "the thing speaks for itself." As one of the astronauts said, "start with what worked on Apollo, and then prove to me why something should be different." The authors likewise feel that the information gleaned from Apollo's operational experiences are relevant even though the exploration missions have different objectives than say "Apollo 18" These recommendations have broad implications for mission directors, engineers, astronauts, physicians, administrators, and anyone involved in exploration missions. To date organizations within the Life Sciences Directorate such as the Human Research Program HRP have taken action on many of the recommendations to develop operational solutions to impacts Apollo identified during their missions. The HRP has funded specific programs, such as the EVA Physiology and Performance Project (EPSP), Exploration Medical Capabilities (ExMC) and Exercise Countermeasures Program (ECP) to develop hardware or systems based on the Apollo Medical Operations Project results. It is important to point out that the EPSP members are currently contributing to the Lunar Architecture Team (LAT) phase 2 study surface and habitat focus elements in addressing the issues related to crew habitat concerns, airlocks/suitlocks, radiation protection, EVA navigation and guidance, suit design and operations, etc.

It is the authors' vision that the recommendations be evaluated by all relevant departments. Also, it is hoped that appropriate recommendations become requirements and go on to improve mission operations. Currently, 48% of the recommendations have created, modified, or validated requirements or are in practice, 52% are being considered or evaluated, and 0% have been rejected. It is incumbent on all who read the paper to keep the 52% from falling by the waste side.

Further work in this area may include additional follow-up or perhaps an ongoing dialogue with the Apollo astronauts to garner their opinions regarding mission operations and implementation of their recommendations. Looking towards the future, with operationally driven outcomes derived from studies such as The Apollo Medical Operations Project, the hope is that humankind will be one step closer to the Constellation goal of exploring the moon, Mars, and beyond.

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Appendices

A. Non-Attributable Access Data Records

B. Non-Attributable Panel Discussion & Post-Panel Responses

C. Apollo Medical Operations Project recommendations Excel® Spreadsheet

D. Apollo Medical Kits from *Biomedical Results of Apollo*[5]

E. Correspondence
    a. Sample invitation letter

F. Meeting Agenda

G. Personal Communications

H. Dr. Bill Carpentier's In-flight Physiological Data